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US Army Corps  
of Engineers

# HARRY S. TRUMAN DAM SPILLWAY AND POWERHOUSE, OSAGE RIVER, MISSOURI

## Hydraulic Model Investigation

### Volume I MAIN TEXT

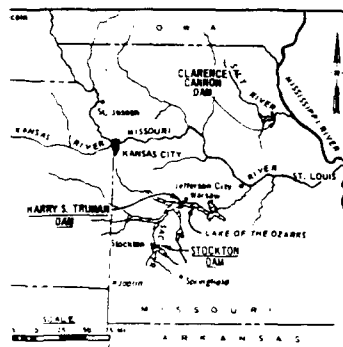
by

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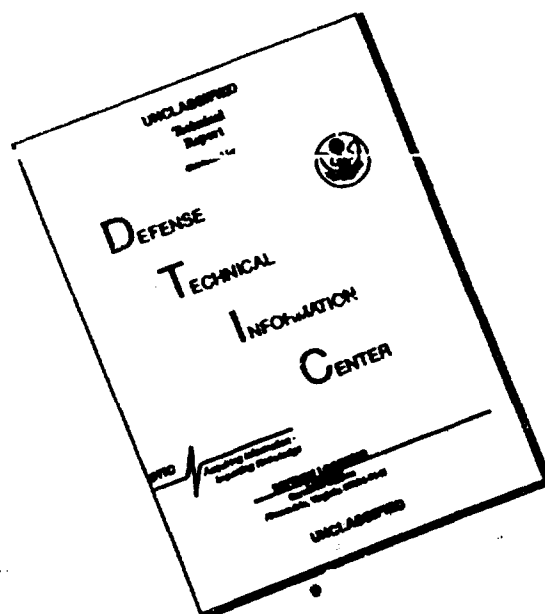
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13. ABSTRACT (Maximum 200 words)  Tests were conducted on a 1:50-scale model of the Harry S. Truman spillway and powerhouse to investigate the cause of and help develop a solution for scour damage on the spillway stilling basin apron. The circulation of rock within the stilling basin (brought in by the flow from downstream) was considered to be the primary cause for the scour on the basin floor based upon the flow patterns observed and measured in the model. Various flow conditions were simulated for both powerhouse and spillway releases to assist in the evaluation of undesirable scour-producing flow patterns. Pressure transducers were used to determine flow pressures in the upstream portion of the basin. All of the test results, along with observations, led to the conclusion that removal of a portion of the flip lip was not a viable solution for the prevention of scour in the stilling basin caused by the circulation of rock during a range of flow conditions. The flip lip is a flow deflector that was added to the downstream face of the prototype spillway during construction to prevent excessive supersaturation of dissolved (Continued)				
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gases in the water downstream of the dam, preventing gas embolism in fish. Various rock traps were tested in conjunction with end sill modifications, none of which were found practical for prototype usage because they caused unsatisfactory flow conditions with larger discharges.

Consideration was given to a concrete overlay to repair the prototype scour and to an overlay of the channel floor just downstream of the end sill followed by periodic prototype inspections.

## PREFACE

The model investigation reported herein was authorized by the US Army Engineer Division, Missouri River (MRD), Omaha, NE, on 23 May 1989 at the request of the US Army Engineer District, Kansas City (MRK). The spillway model tests were accomplished during the period of March 1990 to December 1990 in the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES) under the general supervision of Messrs. F. A. Herrmann, Jr., Chief of the Hydraulics Laboratory; R. A. Sager, Assistant Chief, Hydraulics Laboratory; and G. A. Pickering, Chief of the Hydraulic Structures Division, Hydraulics Laboratory; and under the direct supervision of Mr. N. R. Oswalt, Chief of the Spillways and Channels Branch, Hydraulic Structures Division. The tests were conducted by Messrs. J. R. Leech, Spillways and Channels Branch, and J. Hall, Hydraulic Analysis Branch, Hydraulic Structures Division. This report was prepared by Mr. Leech and assisted by J. R. Rucker, Spillways and Channels Branch, and edited by Mrs. M. C. Gay, Information Technology Laboratory, WES.

During the course of this investigation, Messrs. W. Mellema and A. Swoboda, MRD; and Messrs. P. Barber, W. Linder, D. Huff, T. Wright, S. Hobbs, and J. Conley, MRK, visited WES to observe model tests and correlate results with prototype experiences.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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\* A limited number of copies of Appendix A were published under separate cover. Copies are available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

# CONVERSION FACTORS, NON-SI TO SI (METRIC)

## UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
feet of water (39.2° F)	2.98898	kilopascals
inches	25.4	millimetres
miles (US statute)	1.609344	kilometres
pounds (force) per square inch	6.894757	kilopascals



# HARRY S. TRUMAN DAM SPILLWAY AND POWERHOUSE

## OSAGE RIVER, MISSOURI

### Hydraulic Model Investigation

#### PART I: INTRODUCTION

##### The Prototype

1. Harry S. Truman Dam is a multipurpose project located at mile 175 on the Osage River. The dam is in Benton County, MO, about 1-1/2 miles\* south-west of Warsaw, MO (Figure 1), in the headwaters area of the Lake of the Ozarks. The purposes of the project are to provide flood control, hydro-electric power, recreation, and fish and wildlife habitat. The principal features of the project plan are an earth embankment, a four-gate overfall

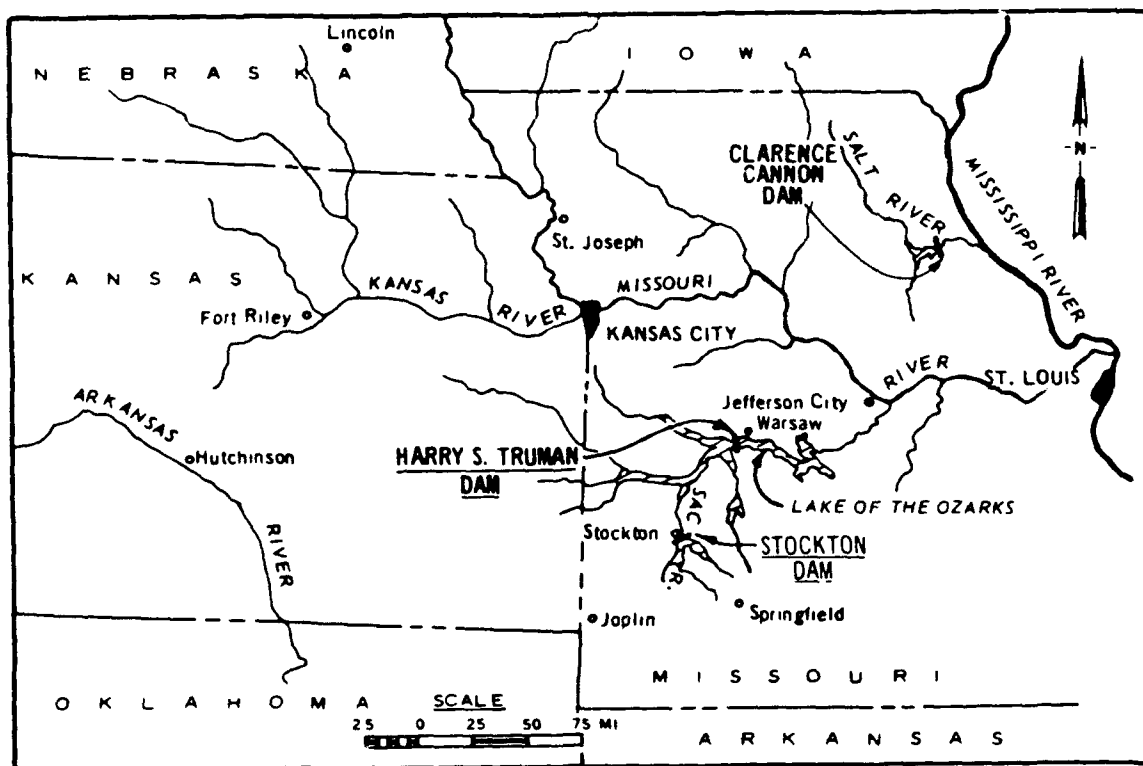


Figure 1. Vicinity map

\* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

ogee spillway, and a hydropower installation (Figure 2). The overall length of the concrete sections and earth embankment is approximately 5,000 ft; the height of the dam above the riverbed is about 98 ft.

2. The ogee spillway section with a crest elevation of 692.3\* is designed to pass the spillway design discharge of 284,000 cfs at a head of 58.8 ft above the crest. Flows over the spillway are controlled by four 40-ft-wide by 47.3-ft-high tainter gates. The piers supporting the gates are 10 ft wide, making the gross length of the weir 190 ft. The weir profile is designed to conform to the lower nappe shape of a weir with a 2V:1H\*\* upstream slope at a design head of 43 ft, which is approximately 76 percent of the 58.8-ft head required to pass the spillway design discharge. That portion of the weir upstream from the crest is formed by radii of 22.79, 9.37, and 2.09 ft, and the downstream portion follows the curve described by the equation  $y = x^{1.825}/43$ . A general plan with model limits of the portion of the project investigated in this study is shown in Plate 1. A 7-ft-wide horizontal flip lip developed during previous model tests† to prevent gas supersaturation downstream of the spillway was built on the spillway face at el 655.0.

3. The stilling basin (Plate 2) consists of a 183-ft-long horizontal apron at el 612.0, surmounted by two staggered rows of 16.5-ft-high baffle piers and a 6-ft-high end sill. The left training wall extends the full length of the basin with its top at el 682.0 and has a 4V:1H slope on the inside face. The powerhouse (Plates 2 and 3) confines flow on the right side of the basin and is terminated by a divider wall, with its top at el 677.0, which separates the powerhouse tailrace and the stilling basin (Figures 2 and 3). A cross section of the powerhouse as represented in the model is shown in Plate 3.

#### Purpose of Model Study

4. The primary purpose of these hydraulic model tests was to determine

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\* All elevations (el) and stages cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

\*\* Slope shown as vertical on horizontal.

† Glenn A. Pickering and D. Bruce Murray. 1979 (Nov). "Model Study of Harry S. Truman Spillway, Osage River, Missouri; Hydraulic Model Investigation," Technical Report HL-79-20, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

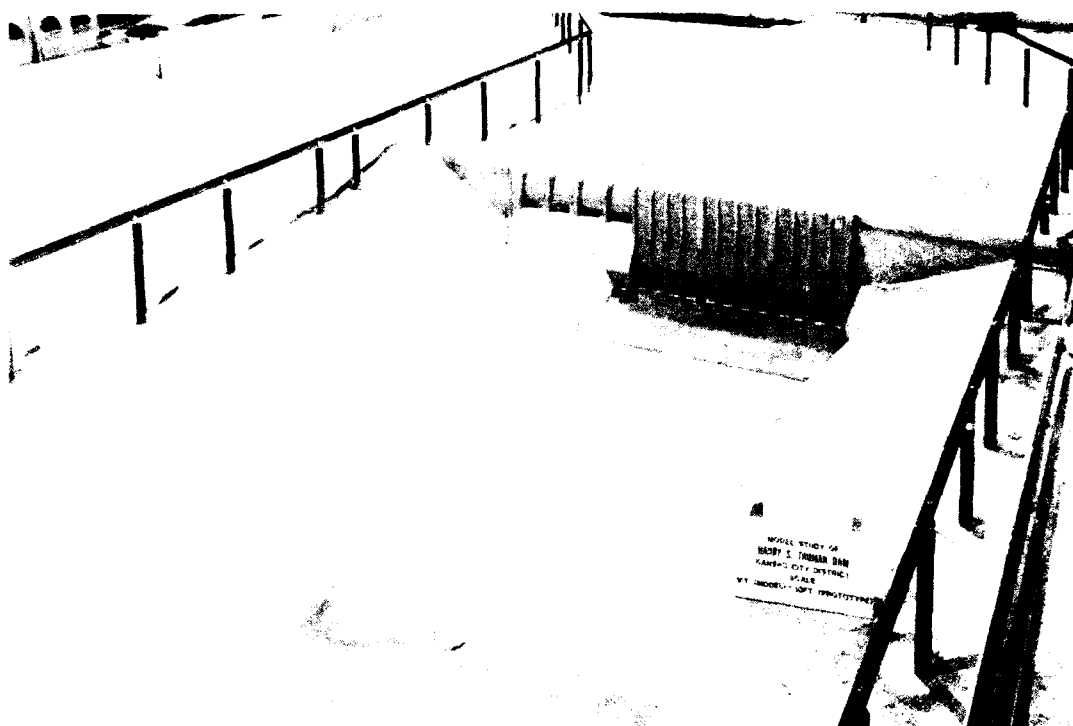


Figure 2. Approach to spillway and powerhouse looking downstream

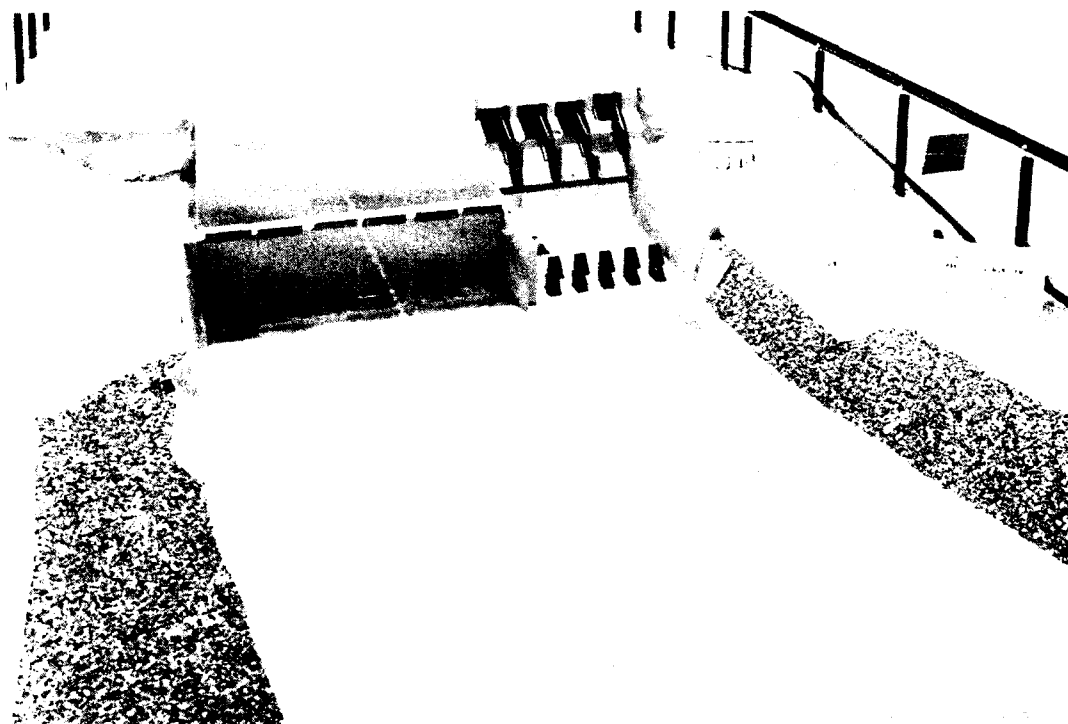


Figure 3. Powerhouse and spillway looking upstream

the cause of scour damage (erosion) on the stilling basin floor and to develop a solution to the scour problem.

#### Scope

5. This model was used to simulate operating conditions for both spillway and powerhouse flows whereby flow patterns could be observed and measured for determining the causes of erosion on the face of the spillway and in the stilling basin. Measurements of hydrostatic pressures, instantaneous pressures, and flow velocities and direction were taken to assist in this determination. Stone displacement tests were used to confirm flow patterns and evaluate ways to achieve an erosion-free stilling basin.

6. Pressure transducers were included on the basin floor to determine the water pressure on the slab in the upstream portion of the basin. Recent model studies have indicated highly fluctuating pressure in the upstream portion of the jump. The pressures in the upstream portion of the basin were needed to evaluate basin slab stability, especially in eroded areas.

7. Various methods of erosion repair such as creating a rock trap by concrete overlays and raised end sills were suggested for evaluation. Prevention of rock entering the basin from downstream by any affordable means to minimize future erosion was desired.

## PART II: THE MODEL

### Description

8. The model (Plate 1, Figure 4), built to an undistorted scale ratio



Figure 4. The 1:50-scale general model looking upstream

of 1:50, reproduced 2,000 ft of the curved approach channel, an 1,800-ft-wide section along the dam (including the spillway and powerhouse), the powerhouse tailrace, and 2,000 ft of the curved exit channel. The weir, gate piers, tainter gates, powerhouse, divider and training walls, and nonoverflow sections were fabricated of sheet metal; the stilling basin was made of water-proofed wood. Topography in the approach and exit was reproduced by cement mortar molded to sheet metal templates.

9. Water used in operation of the model was supplied by pumps, and discharges were measured with venturi meters. Steel rails set to grade along the sides of the flume provided a reference plane for measuring devices. Water-surface elevations were measured with a point gage, and velocities were measured with a pitot tube. Tailwater elevations were regulated by a gate at the downstream end of the flume. Pressures on the spillway crest were

measured with point gages mounted vertically over 3-in. cylinders connected to the piezometers in the model. Nine pressure cells (Plate 4) were mounted flush with the stilling basin apron. The type 4-312 cells were manufactured by Bell and Howell and had a range of 50 psia. The natural frequency was 8,000 Hz for 26 psi ( $\pm 15$  psid).

#### Scale Relations

10. The accepted equations of hydraulic similitude based on the Froudian relations were used to express mathematical relations between dimensions and hydraulic quantities of the model and the prototype. General relations for transference of model data to prototype equivalents are as follows:

<u>Dimension</u>	<u>Ratio</u>	<u>Scale Relation Model:Prototype</u>
Length	$L_r$	1:50
Area	$A_r = L_r^2$	1:2,500
Velocity	$V_r = L_r^{1/2}$	1:7.0711
Discharge	$Q_r = L_r^{5/2}$	1:17,677

### PART III: TESTS AND RESULTS

#### Existing Flow Conditions

11. Initial tests consisted of documenting flow conditions in the model with the existing structure, some of which have never occurred in the prototype. Discharges in this report are total discharges (except where specified). The total discharge was a combination of spillway and powerhouse releases. Model vertical velocity profiles were obtained for nine stations across the spillway and three positions for each station (Plate 5). Tests consisted of documenting flow patterns and measuring velocities for the following flow conditions:

- a. Powerhouse units 1-5 operating with a discharge of 29,000 cfs (unit 6 closed), spillway gates 1-4 operating with a 6.2-ft gate opening passing 32,000 cfs, pool el of 736.7, and a tailwater el of 664.5. Total discharge was 61,000 cfs.
- b. Powerhouse units 1-5 operating with a discharge of 29,000 cfs (unit 6 closed), spillway gates 1-4 operating with a 7.7-ft gate opening passing 47,000 cfs, pool el of 736.7, and a tailwater el of 665.4. Total discharge was 76,000 cfs.
- c. Powerhouse units 1-5 operating with a discharge of 29,000 cfs (unit 6 closed), an uneven spillway operation passing 49,000 cfs (gates 1 and 2 open 4.7 ft, gate 3 open 8.7 ft, gate 4 open 12.7 ft), pool el of 738.7, and a tailwater el of 665.3. Total discharge was 78,000 cfs.
- d. Powerhouse units 1-6 operating with a discharge of 32,500 cfs, spillway gates 1-4 operating with a 19.0-ft gate opening passing 100,000 cfs, pool el of 742.0, and a tailwater el of 668.3. Total discharge was 132,500 cfs.
- e. Powerhouse units 1-6 closed, spillway gates fully open passing 229,000 cfs, pool el of 742.0, and a tailwater el of 675.0. Total discharge was 229,000 cfs.
- f. Powerhouse units 1-6 closed, spillway gates fully open passing 284,000 cfs, pool el of 751.0, and a tailwater el of 678.0. Total discharge was 284,000 cfs.

All velocities were measured with a pitot tube.

12. Velocities and flow patterns determined for a total discharge of 61,000 cfs are shown in Plates 6-14. Velocity stations are shown in Plate 5. Flow along the channel bottom was upstream due to the flip lip (Plate 15) on the downstream quadrant of the spillway causing a surface jet to create an under roller in the stilling basin. Loose rock on the downstream channel

bottom could be pulled into the stilling basin due to the strong upstream velocities along the bottom. Plates 16-24 present velocities for a total discharge of 76,000 cfs. The under roller still existed with a discharge of 76,000 cfs and was more concentrated in the middle of the stilling basin. Plates 25-33 show flow conditions and velocities for a total discharge of 78,000 cfs with an uneven gate operation. The under roller existed downstream from the lower gate openings (sta 1-5 across spillway). Flow downstream from the larger gate opening plunged over the flip lip and eliminated the roller on that side of the stilling basin (sta 6-9 across spillway). Plates 34-42 present the velocities for a discharge of 132,500 cfs. The jet plunged and eliminated the under roller. Velocities at position 3 did not go to the surface due to the hydraulic jump causing a very turbulent zone. Plates 43-51 present the velocities with a discharge of 229,000 cfs showing the satisfactory flow conditions. The under roller did not occur with 229,000 cfs at pool el 742.0 and tailwater el 675.0.

#### Training Wall Extension

13. Left training wall modifications are currently under construction. The modifications are required to minimize erosion of the left bank during high spillway discharges. The modifications were added to the model to determine if they would change flow characteristics in the basin. The location of the existing warped wall section is shown in Plate 52 and Figure 5. The warped wall was also raised (Plate 53) to keep waves during high flow conditions from riding over the top of this section. Details of the training wall extension are shown in Plate 54. Velocities measured at selected locations and discharges with the modified wall in place are shown in Plates 55-69. Surface flow patterns are documented in Photos 1-6 with the modified training extension. Although the velocities were somewhat different in some locations, as would be expected when measuring velocities in very turbulent areas in the stilling basin, flow patterns were not changed. Thus, the modified training wall had minimal effects on flow conditions.

14. Wave action over the top of the training wall extension impacted on and scoured the 48-in. riprap blanket behind the warped wall with discharges of 229,000 and 284,000 cfs in the model.

15. Soundings taken in the prototype indicated scour damage on the



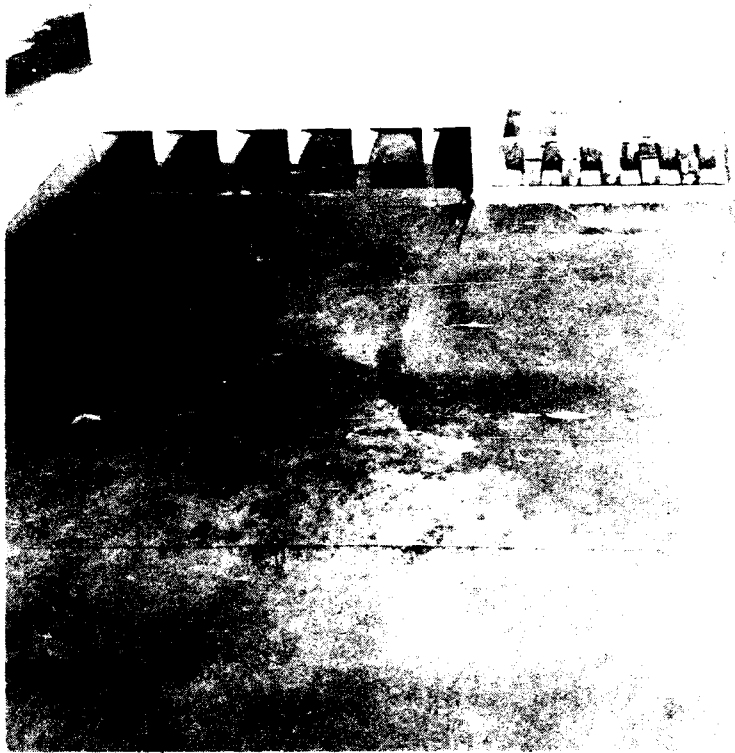


Figure 5. Modified training wall extension

stilling basin floor in the vicinity of the spillway toe curve behind gates 1 and 4. A rock sample, simulating the 12- to 24-in. riprap taken off the overbank side slope, was placed on the adverse slope of the model immediately downstream of the end sill. A test with a total discharge of 61,000 cfs caused the rock to displace to the location of the scour damage (Photo 7) due to the under roller caused by the flip lip.

#### Rock Trap Tests

16. Plans to stop the rock from entering the basin consisted of building a rock trap (Plate 70). Plate 71 shows details of five types of traps tested. The type 1 rock trap successfully trapped the 12- to 24-in. rock when it was placed on the downstream side slope (Plate 72); however, during a test with rock already in the basin (Plate 73), the rock was not washed off. Rock already in the basin was deposited in the same location of the damage in the prototype. With a 200,000-cfs spillway discharge, the type 1 rock trap

allowed the rock in the basin to be washed off, as shown in Plates 74 and 75. The height of the end sill was raised by 6 ft with the type 1 rock trap in place. This configuration trapped the 12- to 24-in. rock downstream of the 6-ft end sill addition for a spillway discharge of 32,000 cfs (Plate 76) and washed the rock already in the basin out for a spillway discharge of 200,000 cfs (Plate 77).

17. Tests to evaluate the type 2 rock trap (Plate 71) are presented in Plates 78-81. The type 2 trap performed basically the same as type 1. Plates 80 and 81 show that increasing the spillway discharge to between 61,000 and 90,000 cfs dislodged the rock already in the stilling basin; however, the rock did not totally wash out over the type 2 rock trap.

18. Further evaluation by the sponsor of the prototype material being removed from the stilling basin indicated that the material was much smaller than was being tested in the model. The prototype material ranged from 2- to 6-in. stones. At this point in the model study the approach to a solution was modified to reflect the smaller material believed to be involved with the problem. The smallest model material needed to represent this material was determined to be 1 mm. The use of this material size in the model to simulate prototype material is questionable, approaching scale effects in the model. However, the 2- to 6-in. rock size was accepted as a viable material for the rock trap tests, and the small model material was used as a comparative evaluation of the different designs.

19. The types 1-5 rock traps (Plate 71) were tested and failed to trap the smaller material. Plates 82 and 83 present the results of displacement tests using the 2- to 6-in. stone size for the type 5 rock trap. The type 5 rock trap failed to trap all of the material. Plates 84 and 85 show the results of tests with the type 5 rock trap and a 12- to 24-in. stone size. Since the type 5 trap used a 16-ft-high wall, questions arose about whether a wall of this height could be feasibly anchored in the wet. Also, the type 5 rock trap adversely influenced the stilling basin performance for the 200,000-cfs spillway discharge.

#### Stone Displacement Tests with Modified End Sill

20. Efforts were redirected to modify the end sill (Plate 86) to stop the material from entering the stilling basin. The type 1 end sill (Plate 87)

consisted of raising the existing end sill by 6 ft and adding a back slope (reverse slope) to possibly allow material already in the basin to be washed off. The type 1 end sill was initially tested prior to determining the smaller material in the prototype. Plates 88-90 present the results of tests using the 12- to 24-in. rock and a type 1 end sill. The type 1 end sill was successful in keeping the larger rock out of the basin. Plates 91 and 92 present the results using the type 2 end sill for the larger rock sizes. Types 1, 2, and 3 were unsuccessful in keeping the 2- to 6-in. material out of the stilling basin. Discharges that produced the under roller caused by the flip lip were the conditions that pulled material upstream into the stilling basin. Results of tests with the type 3 end sill are presented in Plates 93-95. Material washed over this end sill into the stilling basin.

21. The 2- to 6-in. rock was placed on the adverse slope behind the powerhouse and tested with a spillway discharge of 80,000 cfs. The stilling basin remained clean for this test condition.

22. Stone displacement tests with the as-built stilling basin were conducted for several combinations of operating conditions, as documented in Plates 96-100. Test 23 (Plate 96) consisted of placing 2- to 6-in. rock at the toe of the spillway trajectory prior to operation. Tests were then run with tainter gate 4 open 1 ft at pool el 730.0 and tailwater el 662.0 and the powerhouse closed. As shown in Plate 96, the small rock stayed within the basin. Test 24 (Plate 97) had 65,000-cfs powerhouse flow, all powerhouse gates open, all four tainter gates fully closed, with pool el 706.0 and tailwater el 662.0. None of the 2- to 6-in. rock placed at the toe of the spillway moved.

23. Three tests conducted for various powerhouse and spillway flows with 2- to 6-in. rock placed on the adverse slope in the powerhouse tailrace resulted in no deposition in the stilling basin, as shown in Plates 98-100.

#### Tests Without Flip Lip

24. Tests were conducted to determine the effect of the flip lip on the spillway on movement of the material in the basin by removing the flip lip in some or all of the spillway bays. The flip lip was placed on the prototype spillway to prevent excessive supersaturation of dissolved gases in the water downstream from the dam to prevent gas embolism in fish. Removal of the

prototype flip lip would be difficult. The flip lip was removed from spillway bays 1, 2, and 3 for test 28 (Plate 101), resulting in about 20 percent of the 2- to 6-in. rock placed downstream of the spillway end sill being swept into the basin. Test 29 (Plate 102), with the same flow conditions, except for 2- to 6-in. rock being placed at the spillway toe, resulted in removal of about 80 percent of the small rock from the stilling basin. Two tests with 2- to 6-in. rock placed downstream of the end sill were conducted for identical flow conditions with a flip lip for only bays 2 and 3, then bays 1 and 4, respectively. Both of these tests allowed some of the small rock deposited downstream of the stilling basin end sill to enter the basin, as shown in Plates 103 and 104.

25. All the flip lip was removed for tests 32 and 33, resulting in only 5 to 10 percent of the small rock entering the downstream end of the stilling basin (Plates 105 and 106).

26. The final test, 34, with 2- to 6-in. rock placed in the basin, as shown in Plate 107, with a flip lip in only gate bay 4 resulted in no movement of stone for the 1-ft gate opening.

27. Engineers from the US Army Engineer Division, Missouri River, and the US Army Engineer District, Kansas City, observed several of the tests with and without the flip lip. All of the test results, along with observations by several people, led to the conclusion that removal of a portion of the flip lip was not a viable solution for the prevention of scour in the stilling basin caused by the circulation of rock during a range of flow conditions.

#### Hydrostatic and Instantaneous Pressures

28. The Kansas City District is considering the construction of an overlay of the stilling basin apron to repair the basin damage and protect the basin from future scour. Tests were conducted to determine pressures and pressure fluctuations on the apron to assist in the design of this overlay. Also, there was speculation that cavitation could possibly have caused some of the damage to the apron.

29. Hydrostatic pressure profiles were obtained with the as-built design for a range of discharges. The location of the static ports (piezometers) is provided in Plates 108-110, and data plots are shown in Plates 111-115. No tendency for cavitation was indicated by the plots.

30. Instantaneous pressure measurements were made in the stilling basin at nine locations, shown in Plate 4 and Figure 6, where some of the worst scour damage had occurred in the prototype. These pressure data and plots for discharges of 61,000, 69,900, 70,000, 132,500, 229,000, and 284,000 cfs are provided in Tables 1-6. Expanded plots are located in Appendix A.

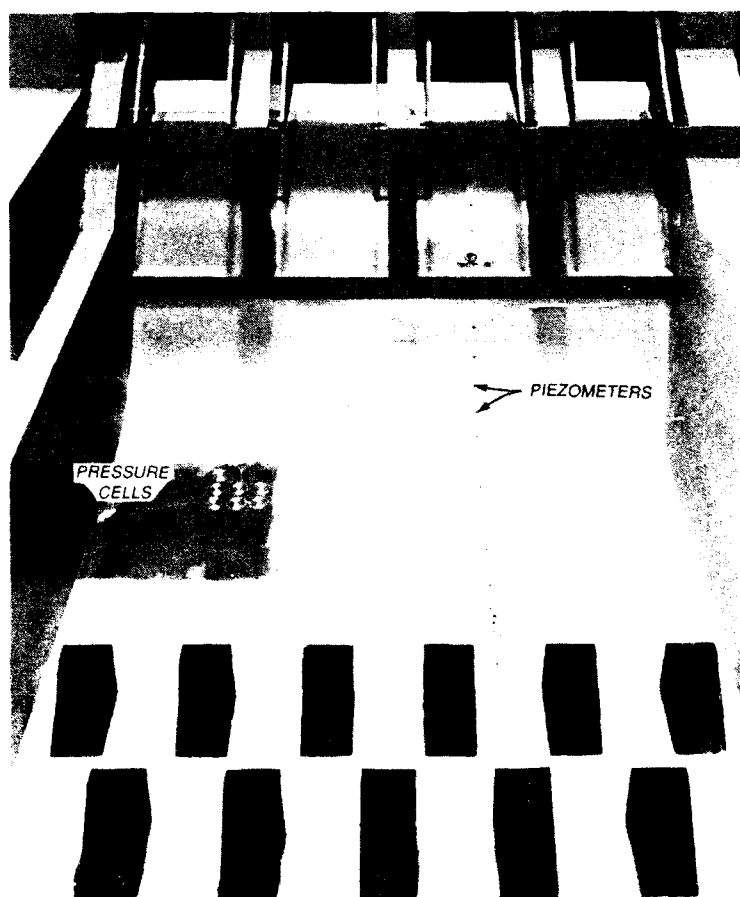


Figure 6. Stilling basin instrumentation

#### PART IV: DISCUSSION AND CONCLUSIONS

31. The primary purpose for this study was to provide assistance in identifying and helping solve the scour problem in the stilling basin. Flow circulation patterns in the spillway stilling basin indicated an upstream submerged roller (reverse flow) beneath the downstream surface flow with spillway discharges up to 80,000 cfs. Observations with flows from 1,000 up to 80,000 cfs indicated that the reverse flow pattern occurred within the stilling basin to varying degrees depending on the discharge. The submerged roller extended the full length of the stilling basin and was caused by flow striking the flip lip on the spillway and deflecting along the water surface. The reverse flow produced velocities capable of transporting material in the area downstream from the stilling basin back into the basin. With discharges higher than about 80,000 cfs, flow plunged over the flip lip and eliminated the reverse roller.

32. Numerous rock transport tests were conducted to identify the adverse circulation patterns and location of rock deposition. Various rock sizes were placed at several locations within the stilling basin and downstream of the basin before operating the spillway and powerhouse with a range of discharges. Results of these tests indicated that the area of deposition and circulation of rock were related to the location of the prototype scour. A single tainter gate opening at normal and moderate pool elevations (up to about el 730.0) releasing 500 cfs will not move debris on the basin floor. Powerhouse discharges alone will not move debris into the basin. Discharges of 200,000 cfs and possibly somewhat lower will flush rock from the basin. Rock was pulled into the basin from the area immediately downstream of the stilling basin to the crown of the adverse slope.

33. A training wall extension was installed on the downstream left bank of the stilling basin to identify any effects this modification might have on the flow circulation patterns. Results of tests with the wall extension indicated no measurable difference in flow patterns.

34. A vertical wall, 4, 6, 8, 10, and 16 ft high, was added to the stilling basin to create a rock trap just downstream of the second row of baffle piers. The wall did not trap 2- to 6-in. rock (prototype) washed into the basin from the downstream channel with lower discharges, and rock already in the basin was not washed out. The rock in the basin was washed into the

rock trap with larger discharges. Additional tests conducted with various rock traps created by raising the end sill heights (6, 8, and 10 ft on a 1V:1H slope) and adding an additional wall downstream of the second row of baffles provided varying degrees of effectiveness. Rock sized 2 to 6 in. washed out of the basin with discharges lower than those required with the vertical walls in the basin; however, the end sill height required to prevent small rock from entering the basin from downstream created a secondary hydraulic jump downstream from the end sill with high discharges. Creating a rock trap with a vertical wall and/or high end sills was not considered an adequate solution due to the potential for adverse flow conditions downstream of the stilling basin during high discharges.

35. Several tests were conducted with the flip lip removed in some or all of the gate bays to determine what effect this would have on movement of material. Tests with the flip lip removed from all bays indicated that very little material would be pulled into the basin. Although removal of the flip lip showed a definite improvement with respect to movement of material into the basin, this was not considered a viable modification by engineers from the Missouri River Division and Kansas City District.

36. Since removing the flip lip, constructing rock traps in the stilling basin, and raising the end sill height were not considered practical solutions to the stilling basin scour problems, the Kansas City District will consider overlaying the basin apron with high-quality concrete and frequently inspecting the prototype structure. Tests were conducted to determine pressures and pressure fluctuations on the basin apron to assist in the structural design of this overlay. No cavitation-producing pressures occurred.

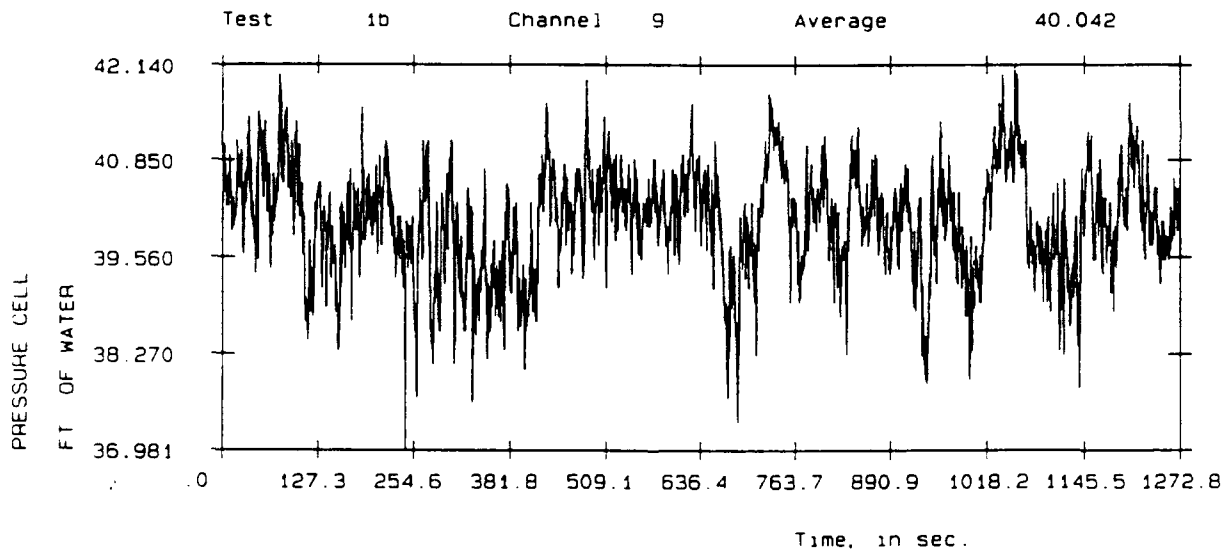
37. Pressure data reveal instantaneous pressures exceeding the tailwater. These pressure spikes are common in turbulent flow regimes where rollers impact on a specific area and then dissipate very rapidly, causing extreme pressures only for an instant in time.

Table 1

Instantaneous Pressure DataPool El 736.7, Tailwater El 664.5, Discharge 61,000 cfs

Probe No.	Pressure Cell Reading, ft of water		
	<u>Minimum</u>	<u>Average</u>	<u>Maximum</u>
1	33.995	38.053	39.488
2	36.178	38.513	40.111
3	38.705	41.293	43.100
4	31.490	34.219	35.625
5	35.474	38.561	40.220
6	34.593	37.179	38.839
7	34.625	37.491	39.046
8	34.633	37.846	39.586
9	36.981	40.042	42.140

Note: Sampling rate 32 samples per second per channel.  
Length of samples 180 sec (prototype).  
Gates 1-4 open 6.2 ft.



Typical plot of actual data

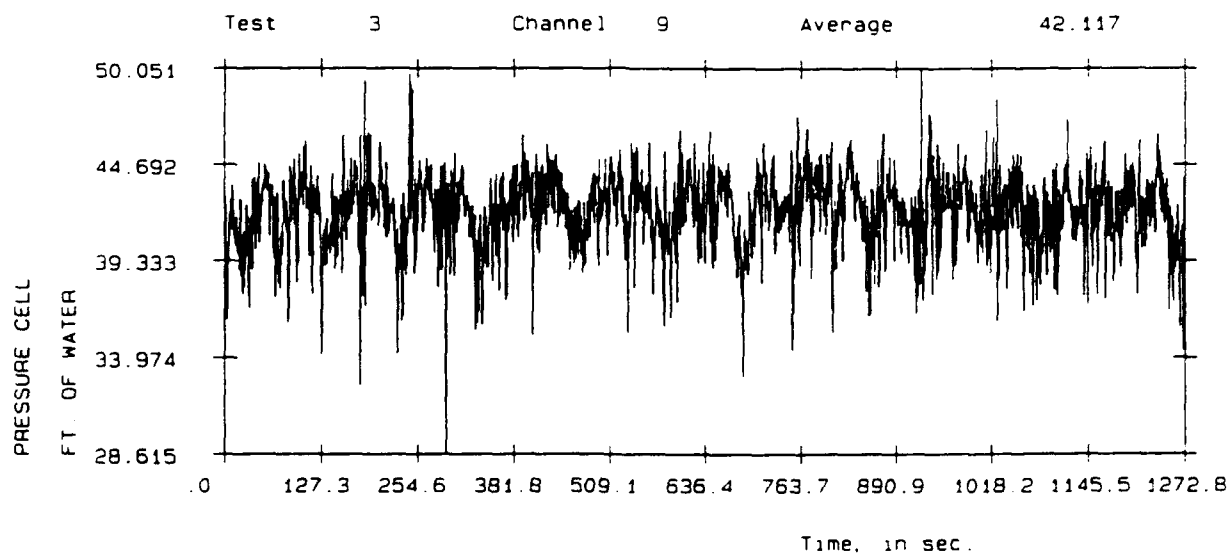


Table 2

Instantaneous Pressure DataPool El 738.7, Tailwater El 665.3, Discharge 69,900 cfs

Probe No.	Pressure Cell Reading, ft of water		
	Minimum	Average	Maximum
1	31.171	38.199	41.615
2	31.470	39.522	45.486
3	35.438	43.856	50.744
4	26.063	35.280	38.868
5	33.143	41.265	45.525
6	30.434	39.243	46.699
7	31.495	36.762	40.733
8	29.341	37.936	44.986
9	28.615	42.117	50.051

Note: Sampling rate 32 samples per second per channel.  
Length of samples 180 sec (prototype).  
Gates 1-4.7 ft, 2-4.7 ft, 3-8.7 ft, 4-12.7 ft open.



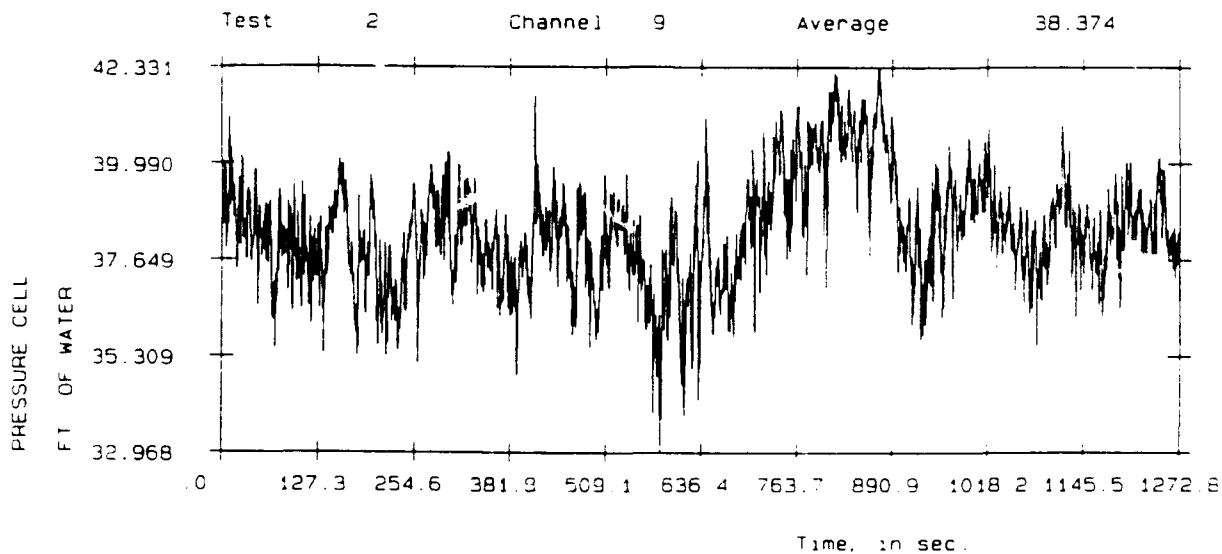
Typical plot of actual data

Table 3

Instantaneous Pressure DataPool El 738.3, Tailwater El 665.4, Discharge 70,000 cfs

Probe No.	Pressure Cell Reading, ft of water		
	<u>Minimum</u>	<u>Average</u>	<u>Maximum</u>
1	30.690	36.501	39.488
2	28.710	36.802	40.111
3	32.307	39.678	43.545
4	23.355	31.930	34.996
5	29.019	36.831	40.283
6	30.654	35.547	39.043
7	28.289	35.815	38.955
8	30.381	36.242	39.539
9	32.968	38.374	42.331

Note: Sampling rate 32 samples per second per channel.  
 Length of samples 180 sec (prototype).  
 Gates 1-4 open 7.7 ft.



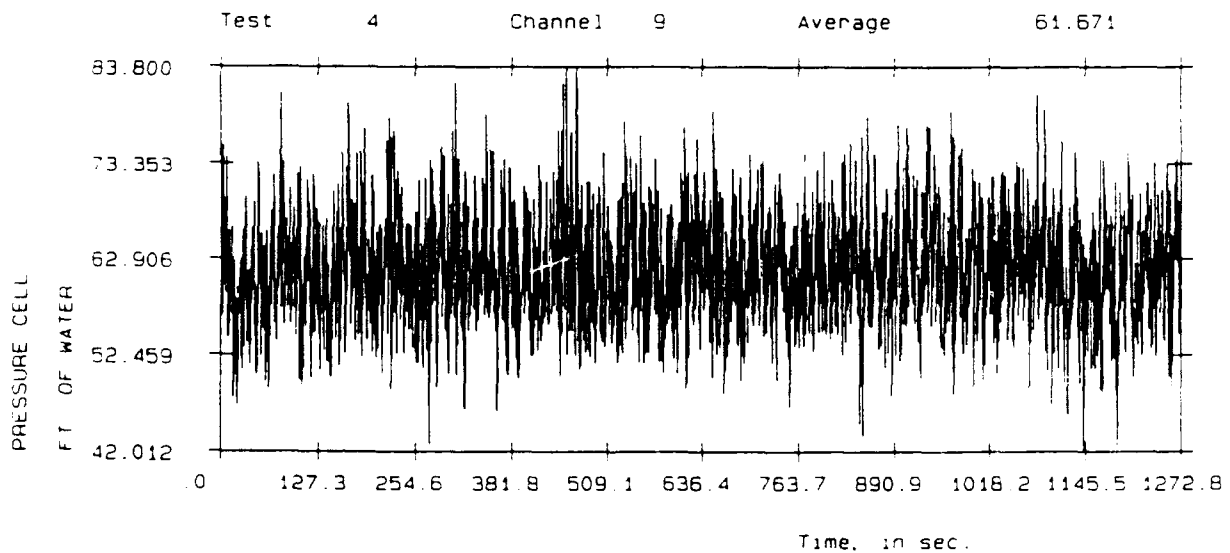
Typical plot of actual data

Table 4

Instantaneous Pressure DataPool El 742.0, Tailwater El 668.3, Discharge 132,500 cfs

Probe No.	Pressure Cell Reading, ft of water		
	Minimum	Average	Maximum
1	35.705	55.717	82.220
2	40.648	58.887	76.909
3	46.585	63.018	79.804
4	31.429	53.122	79.944
5	42.667	62.767	82.925
6	40.490	55.551	72.712
7	35.818	56.786	86.829
8	38.962	59.309	85.524
9	42.012	61.671	83.800

Note: Sampling rate 32 samples per second per channel.  
Length of samples 180 sec (prototype).  
Gates 1-4 open 19.0 ft.



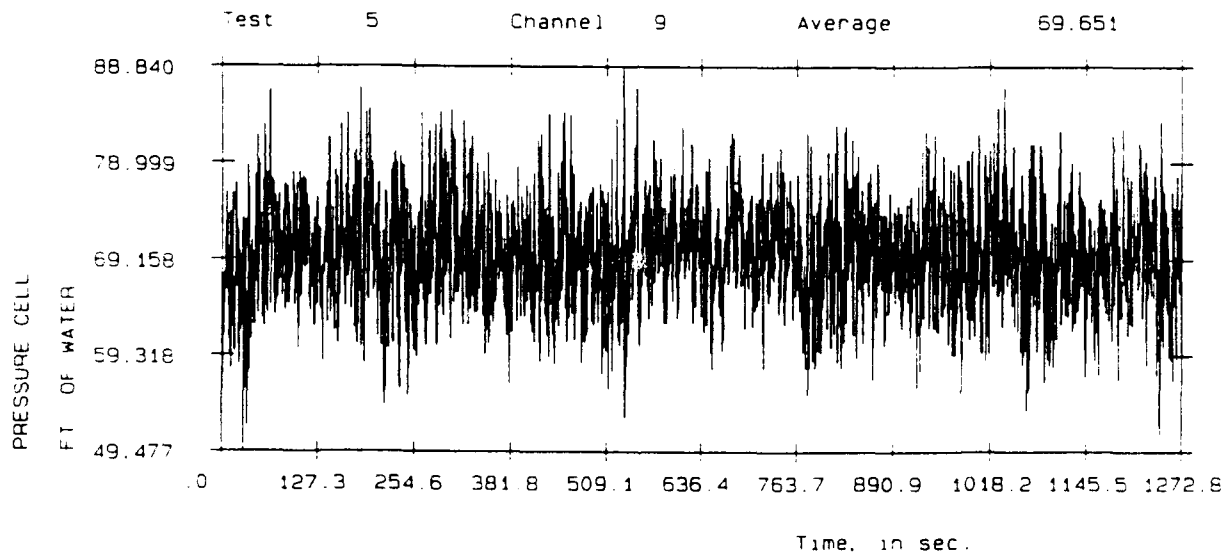
Typical plot of actual data

Table 5

Instantaneous Pressure DataPool El 742.0, Tailwater El 675.0, Discharge 229,000 cfs

Probe No.	Pressure Cell Reading, ft of water		
	Minimum	Average	Maximum
1	42.889	62.663	91.340
2	46.085	66.195	87.783
3	50.356	73.351	93.446
4	35.306	56.253	83.145
5	44.382	68.585	90.418
6	48.649	64.139	82.461
7	39.094	56.823	82.870
8	43.025	61.764	85.384
9	49.477	69.651	88.840

Note: Sampling rate 32 samples per second per channel.  
Length of samples 180 sec (prototype).  
Gates open full.



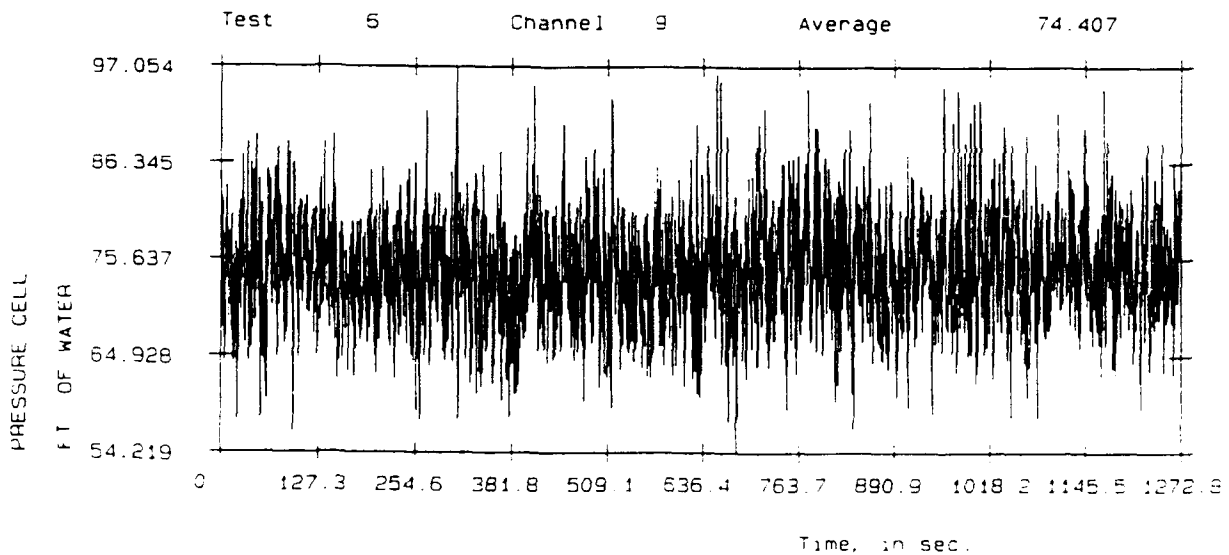
Typical plot of actual data

Table 6

Instantaneous Pressure DataPool El 751.0, Tailwater El 678.0, Discharge 284,000 cfs

Probe No.	Pressure Cell Reading, ft of water		
	<u>Minimum</u>	<u>Average</u>	<u>Maximum</u>
1	46.659	67.276	96.944
2	44.139	69.308	93.020
3	46.424	75.535	95.581
4	45.844	64.527	90.807
5	43.288	70.639	96.086
6	48.083	67.765	85.060
7	41.196	61.902	87.861
8	45.687	66.480	88.964
9	54.219	74.407	97.054

Note: Sampling rate 32 samples per second per channel.  
Length of samples 180 sec (prototype).  
Gates open full.



Typical plot of actual data



Figure 1. Power discharge 34,800 cfs; pool at 706.0;  
tailwater at 694.5; gates 1 & 2 closed



Figure 1. Total discharge of water from pond of 1994  
collected at 100 m radius from pond.







Photo 1. Total discharge of water from pool of 195.12  
collected in 10.0 min. (195.12/10.0 = 19.512)

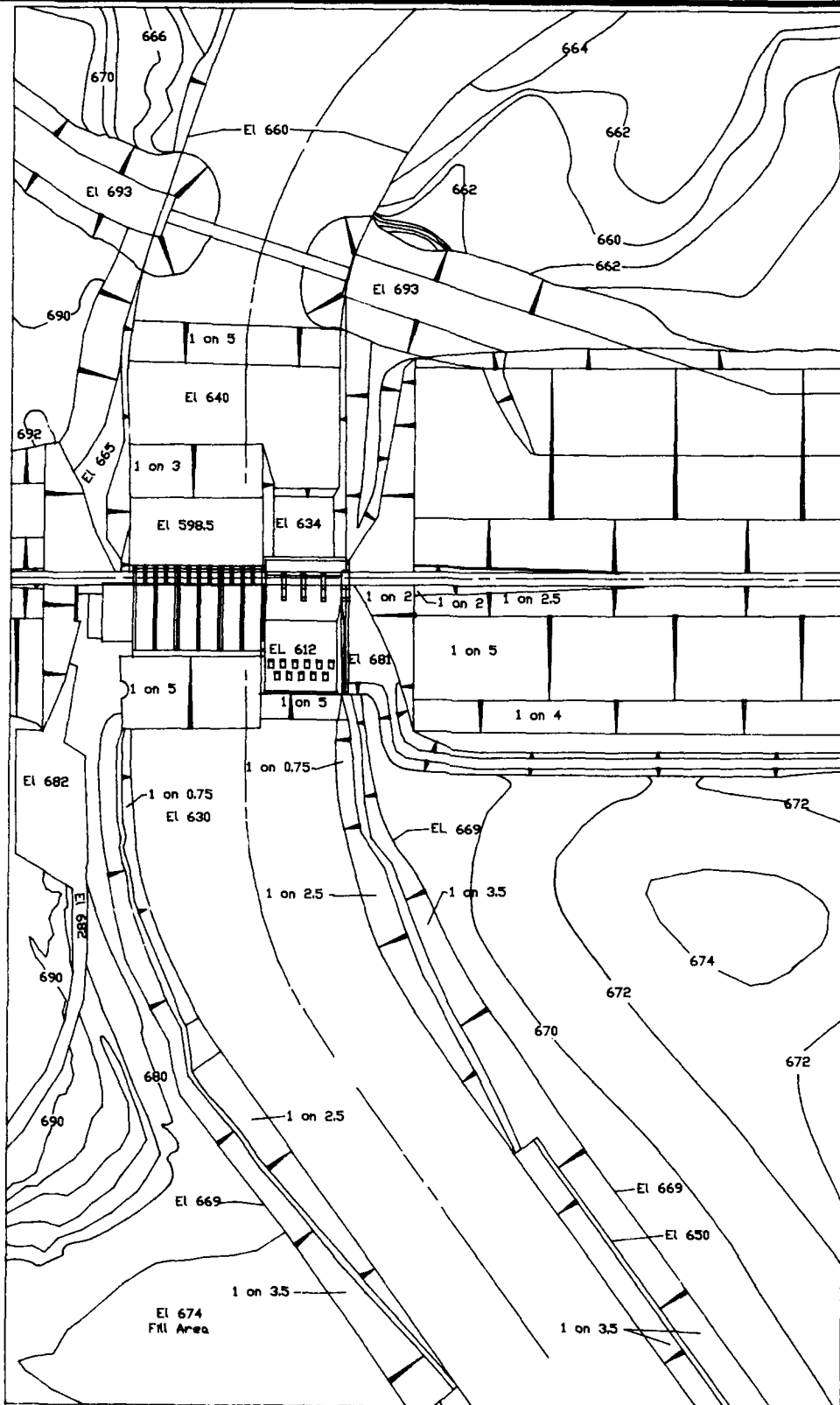


Fig. 1. Pool of water, pool el. 142.0; gate open 19.0 ft.

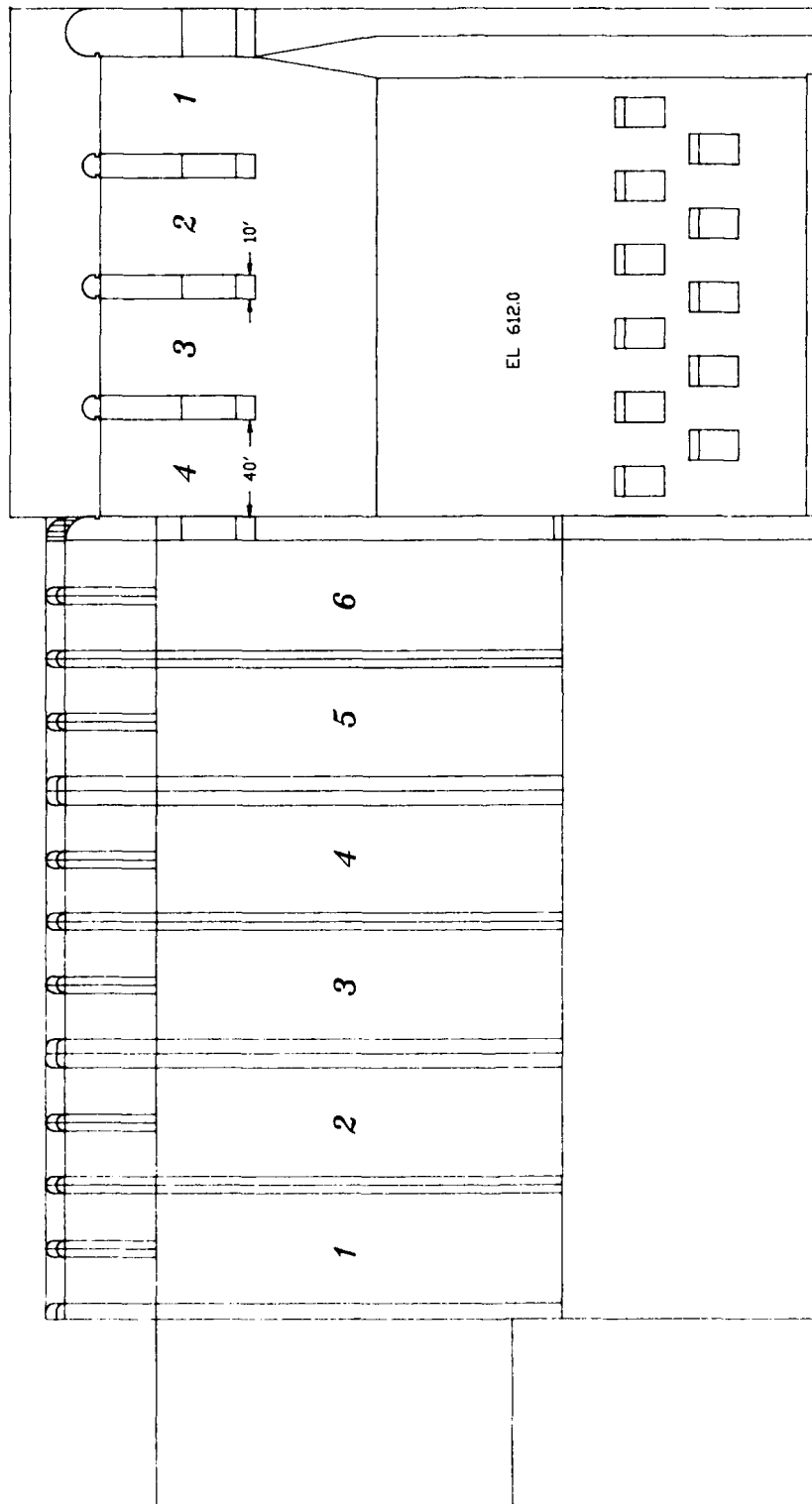
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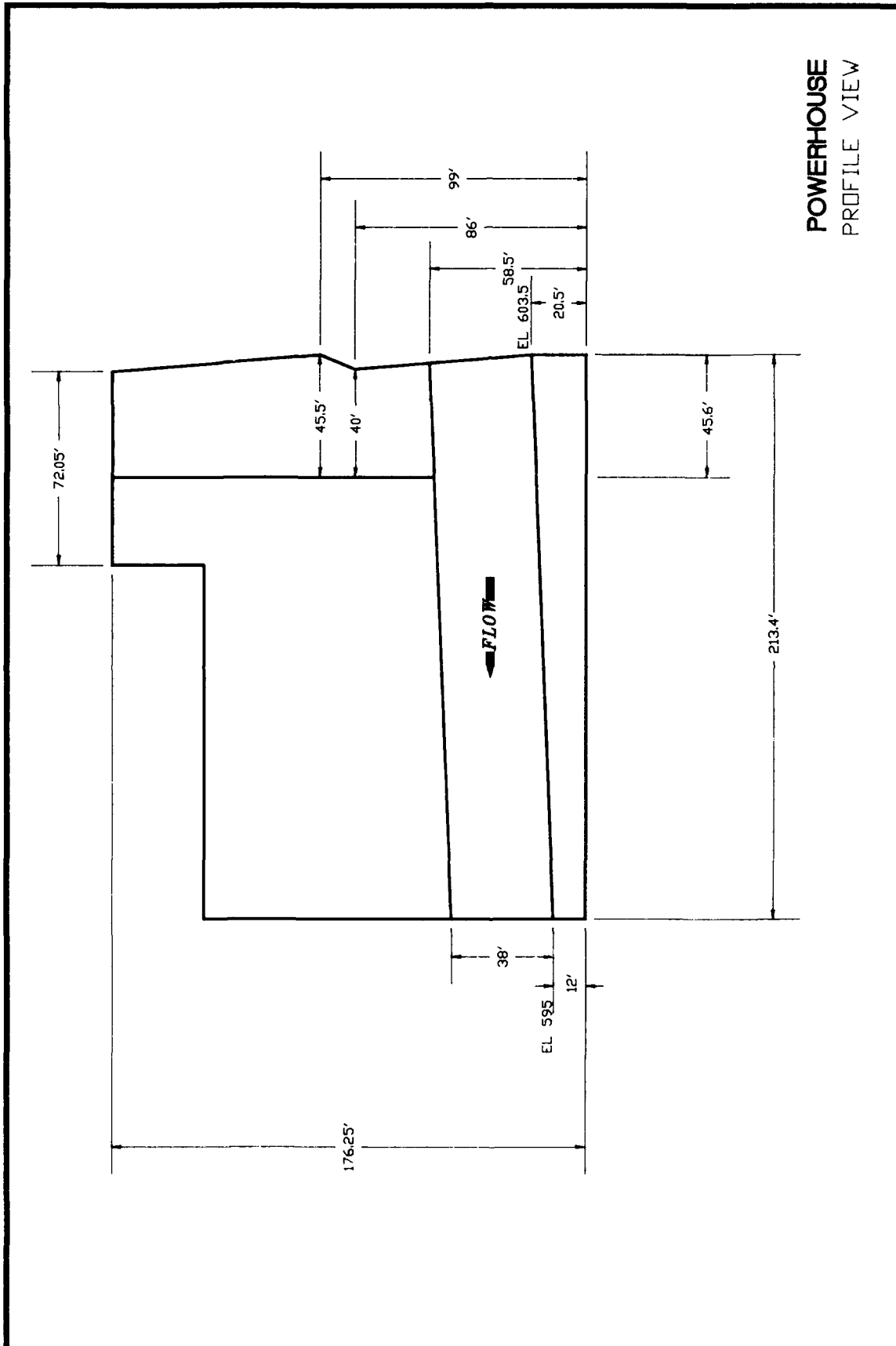
Photo 7. Stilling basin scour damage



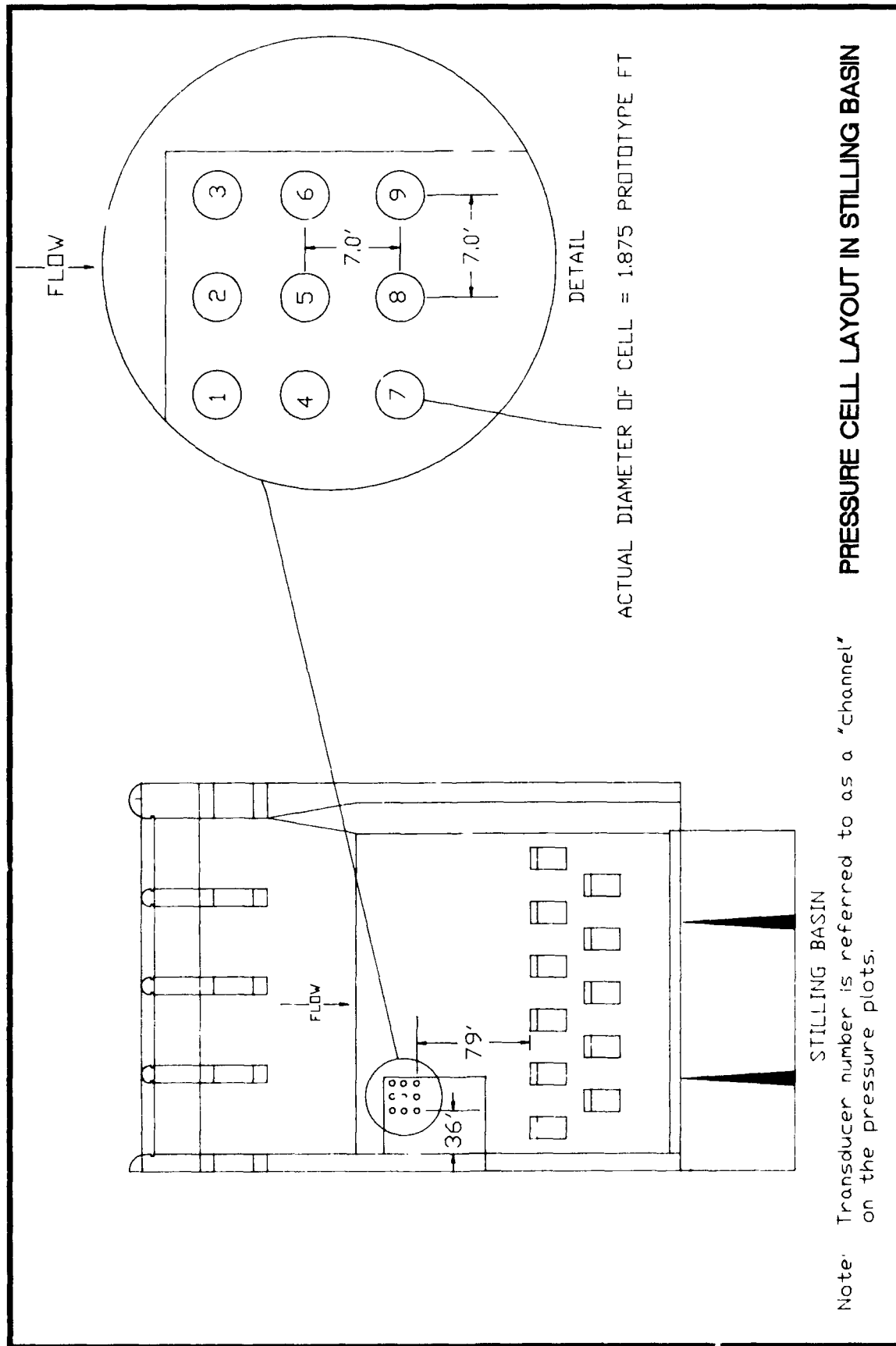
**HARRY S. TRUMAN SPILLWAY**  
MODEL LIMITS



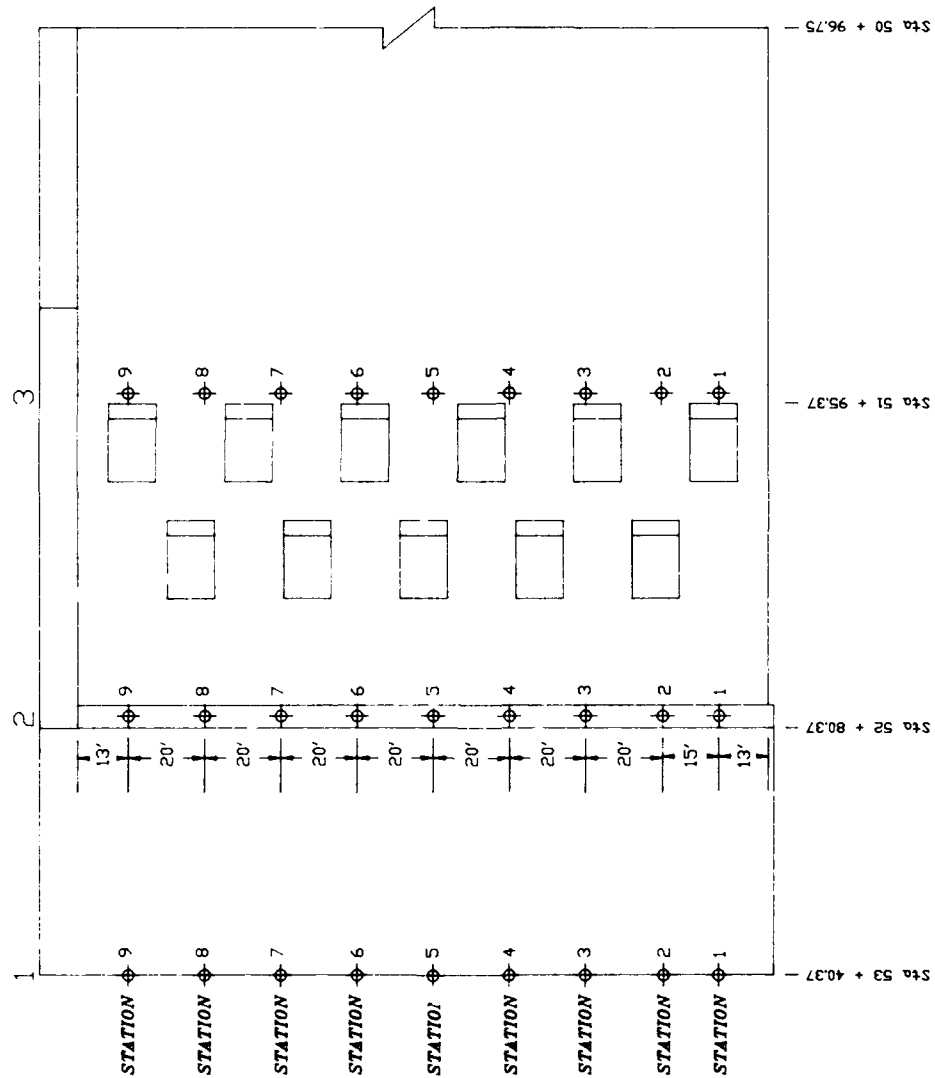
SPILLWAY AND POWERHOUSE  
PLAN VIEW



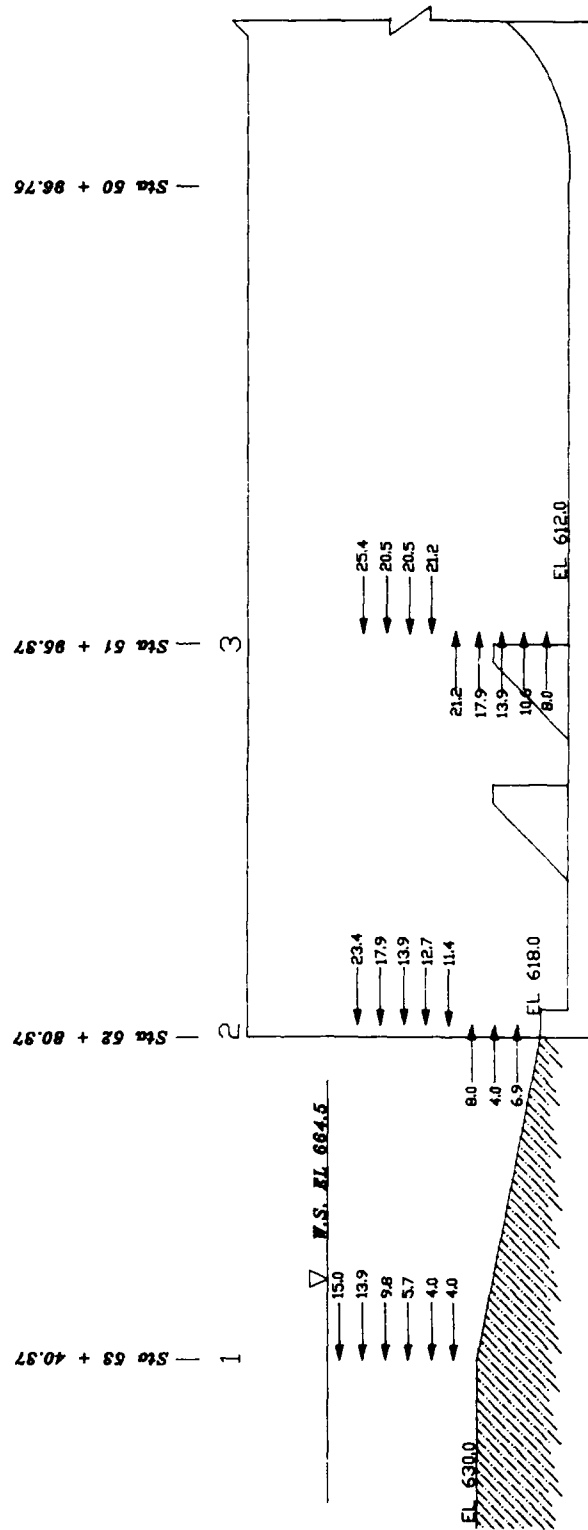
POWERHOUSE  
PROFILE VIEW





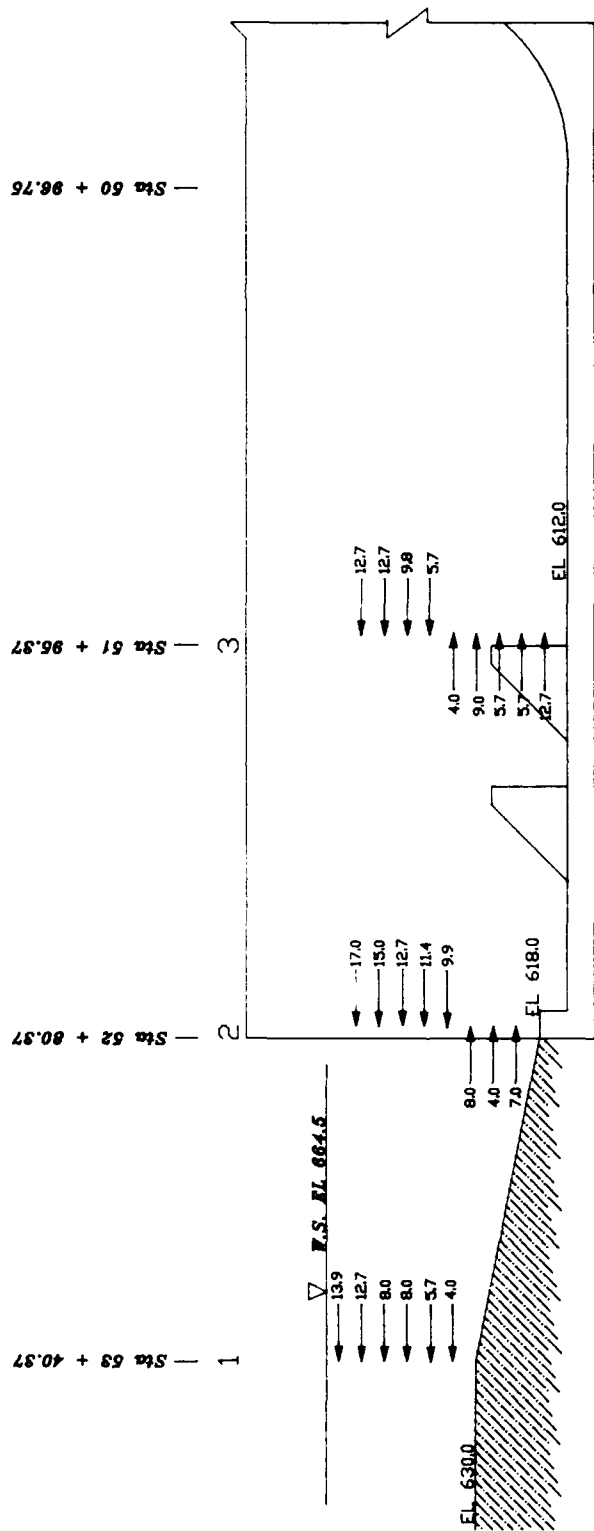


PLAN VIEW OF VELOCITY POSITIONING



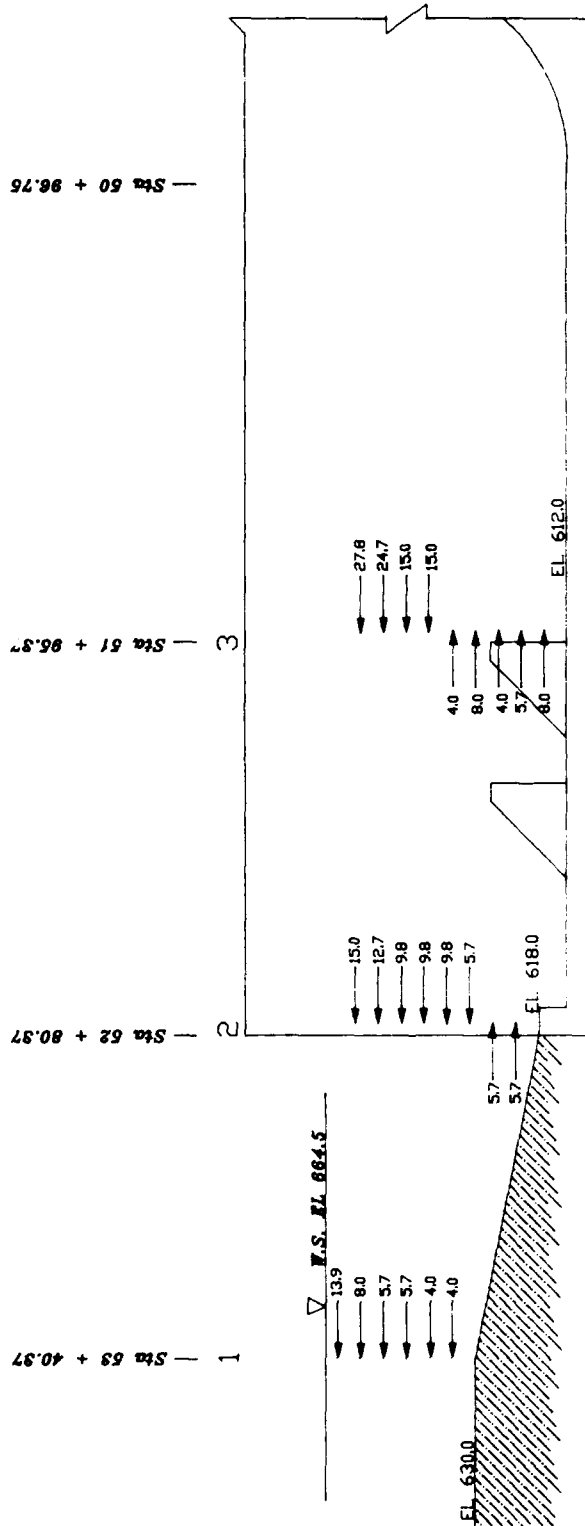
**VELOCITY AND FLOW PATTERNS**  
 STATION 1  
 SPILLWAY DISCHARGE 32,000 CFS  
 POWERHOUSE DISCHARGE 29,000 CFS  
 POOL EL 736.7  
 TAILWATER EL 664.5

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



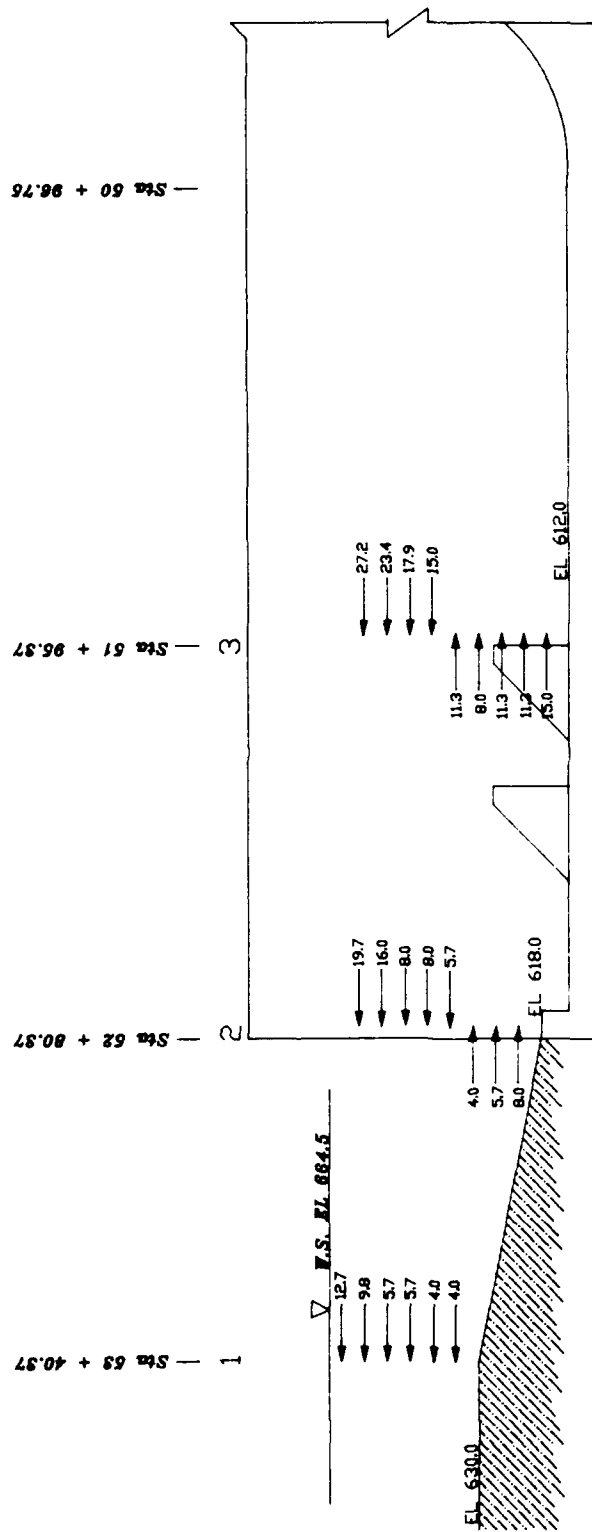
**VELOCITY AND FLOW PATTERNS**  
 STATION 2  
 SPILLWAY DISCHARGE 32,000 CFS  
 POWERHOUSE DISCHARGE 29,000 CFS  
 POOL E- 736.7  
 TAILWATER EL 664.5

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



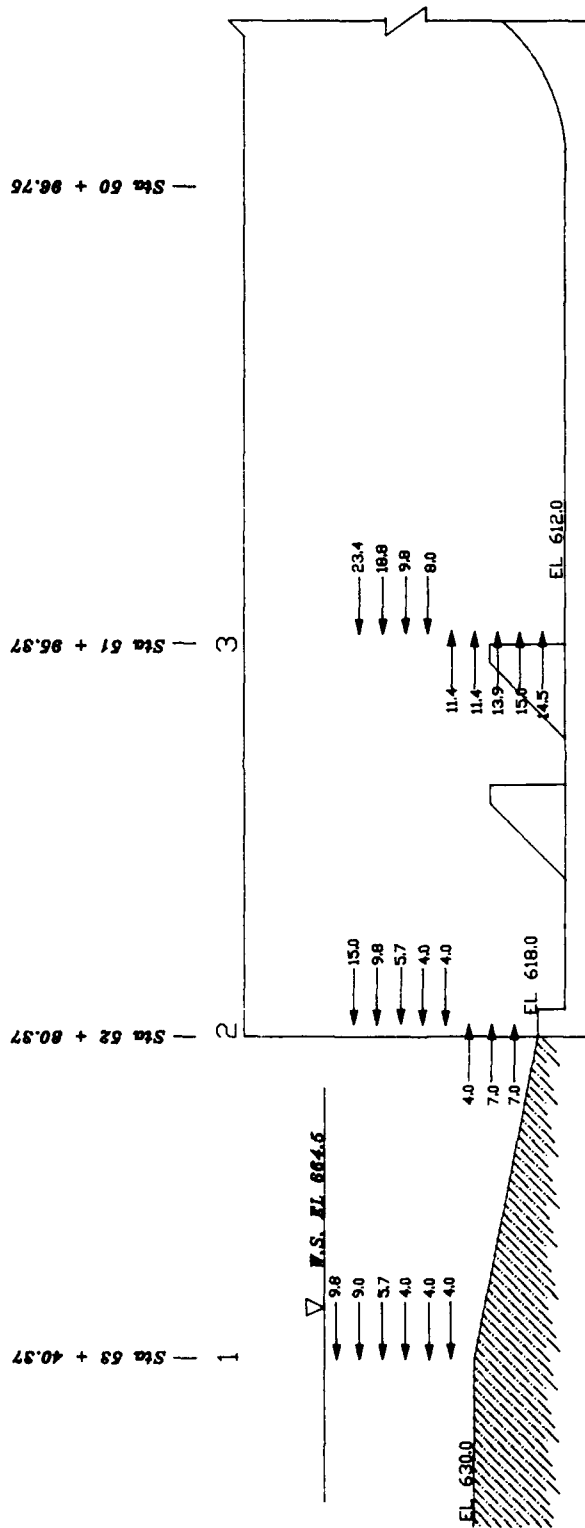
**VELOCITY AND FLOW PATTERNS**  
 STATION 3  
 SPILLWAY DISCHARGE 32,000 CFS  
 POWERHOUSE DISCHARGE 29,000 CFS  
 POOL EL 736.7  
 TAILWATER EL 664.5

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



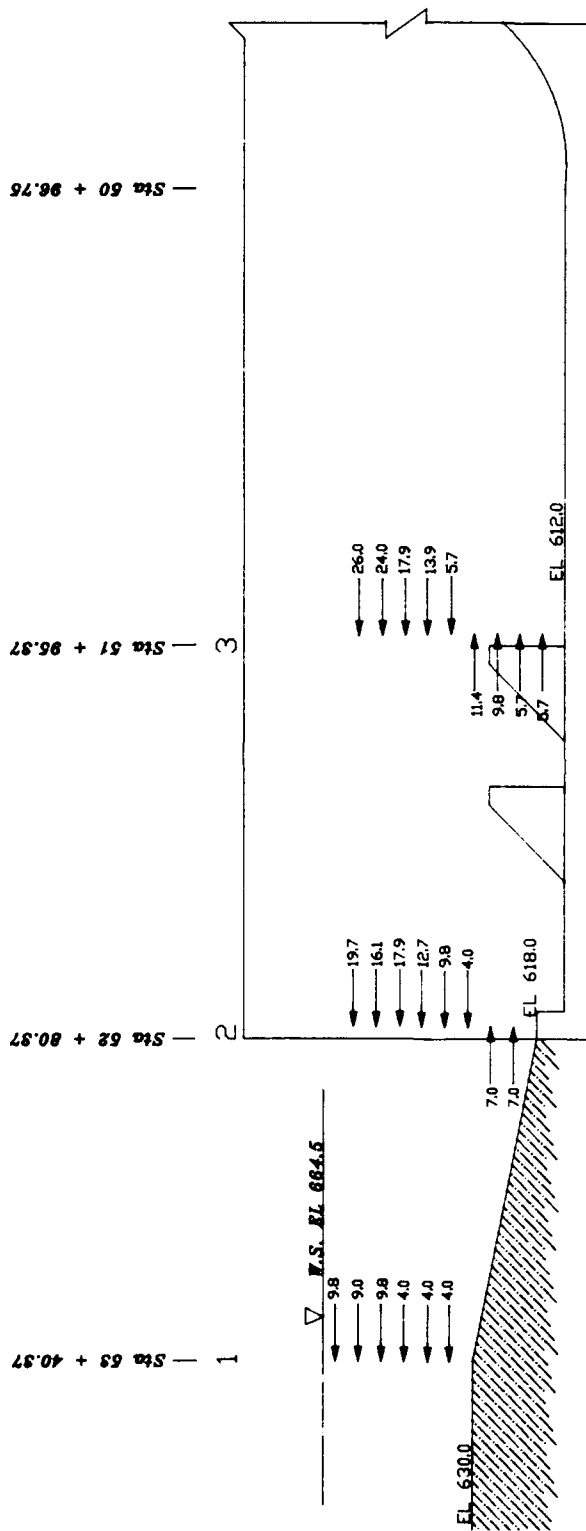
**VELOCITY AND FLOW PATTERNS**  
 STATION 4  
 SPILLWAY DISCHARGE 32,000 CFS  
 POWERHOUSE DISCHARGE 29,000 CFS  
 POOL EL 736.7  
 TAILWATER EL 664.5

NOTE: VELOCITIES IN FEET PER SECOND AND AT  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



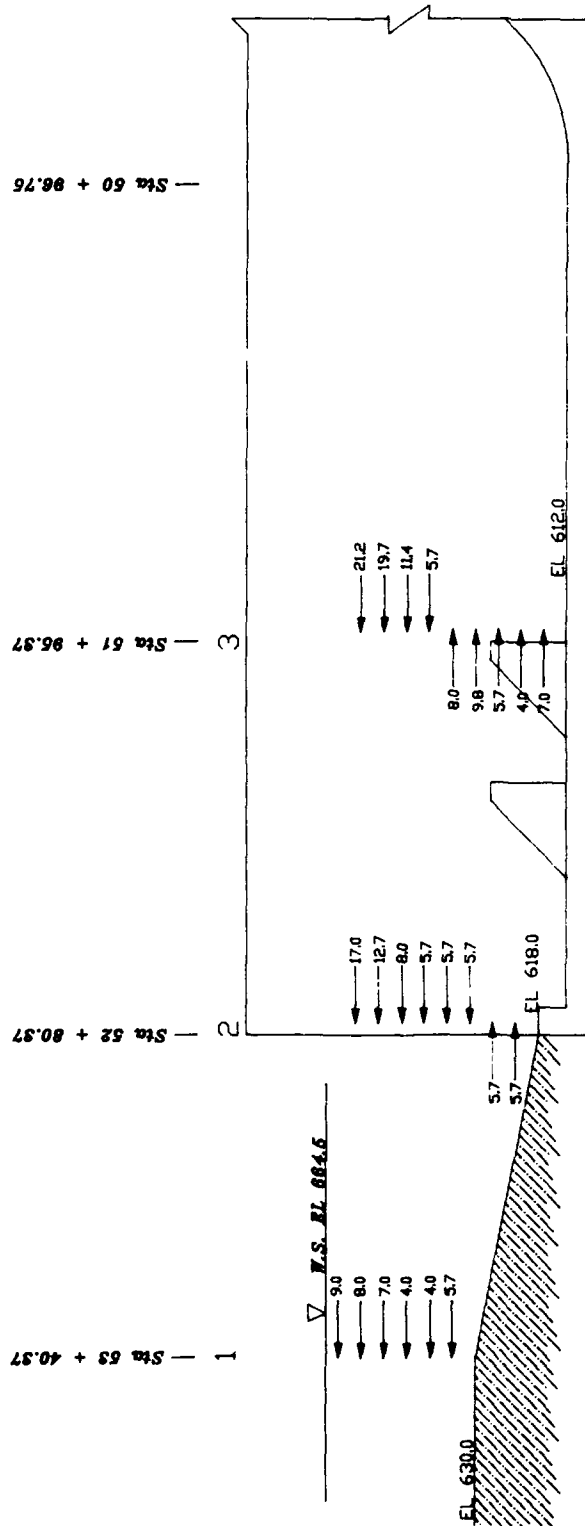
**VELOCITY AND FLOW PATTERNS**  
 STATION 5  
 SPILLWAY DISCHARGE 32,000 CFS  
 POWERHOUSE DISCHARGE 29,000 CFS  
 POOL EL 736.7  
 TAILWATER EL 664.5

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



**VELOCITY AND FLOW PATTERNS**  
 STATION 6  
 SPILLWAY DISCHARGE 32,000 CFS  
 POWERHOUSE DISCHARGE 29,000 CFS  
 POOL EL 736.7  
 TAILWATER EL 664.5

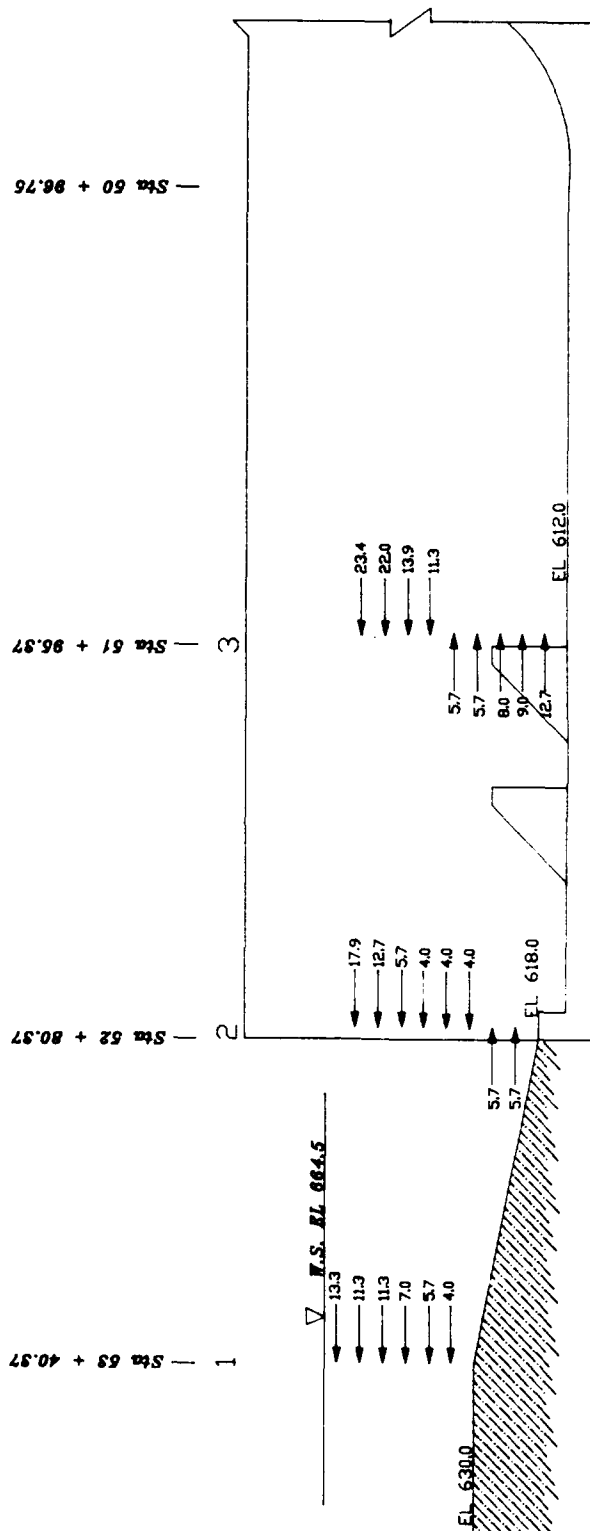
NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



**VELOCITY AND FLOW PATTERNS**  
 STATION 7  
 SPILLWAY DISCHARGE 32,000 CFS  
 POWERHOUSE DISCHARGE 29,000 CFS  
 POOL EL 736.7  
 TAILWATER EL 664.5

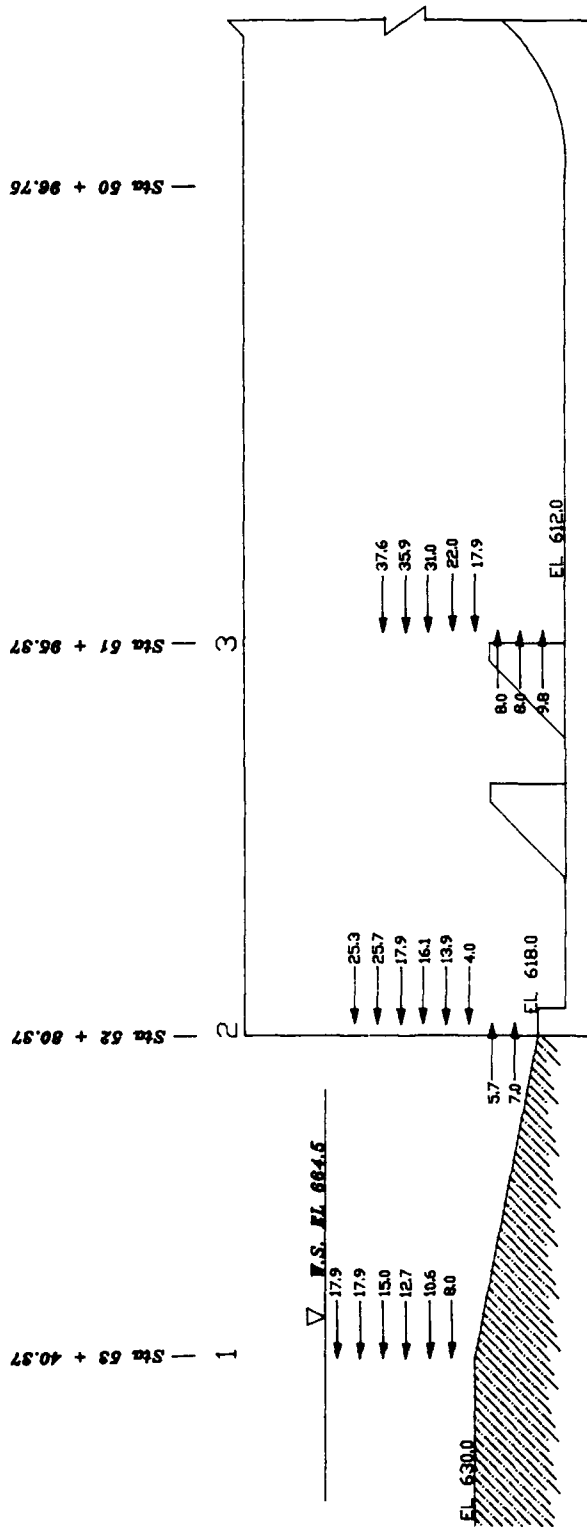
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 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM





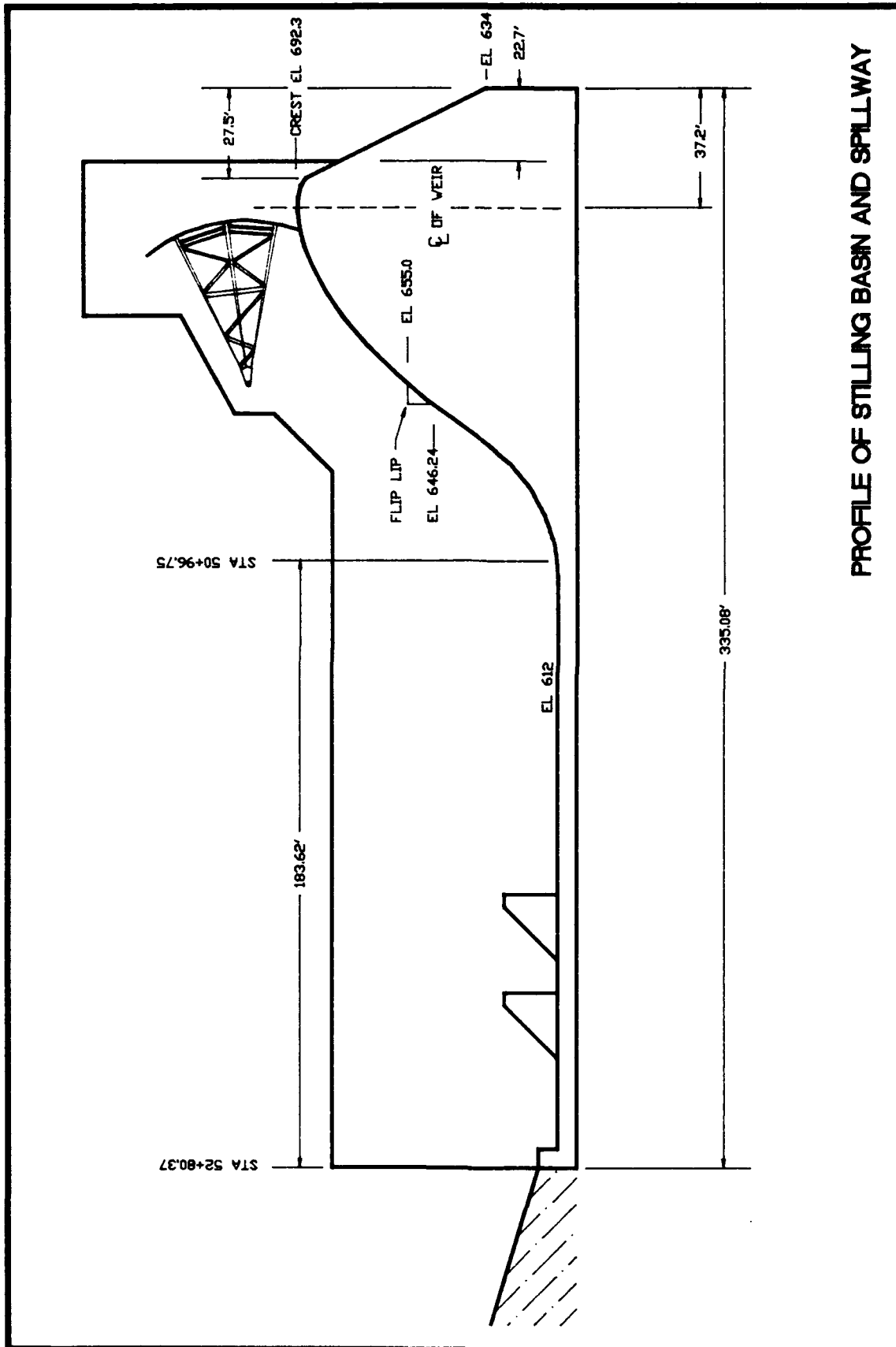
# **VELOCITY AND FLOW PATTERNS** STATION 8 SPILLWAY DISCHARGE 32,000 CFS POWERHOUSE DISCHARGE 29,000 CFS POOL EL 736.7 TAILWATER EL 664.5

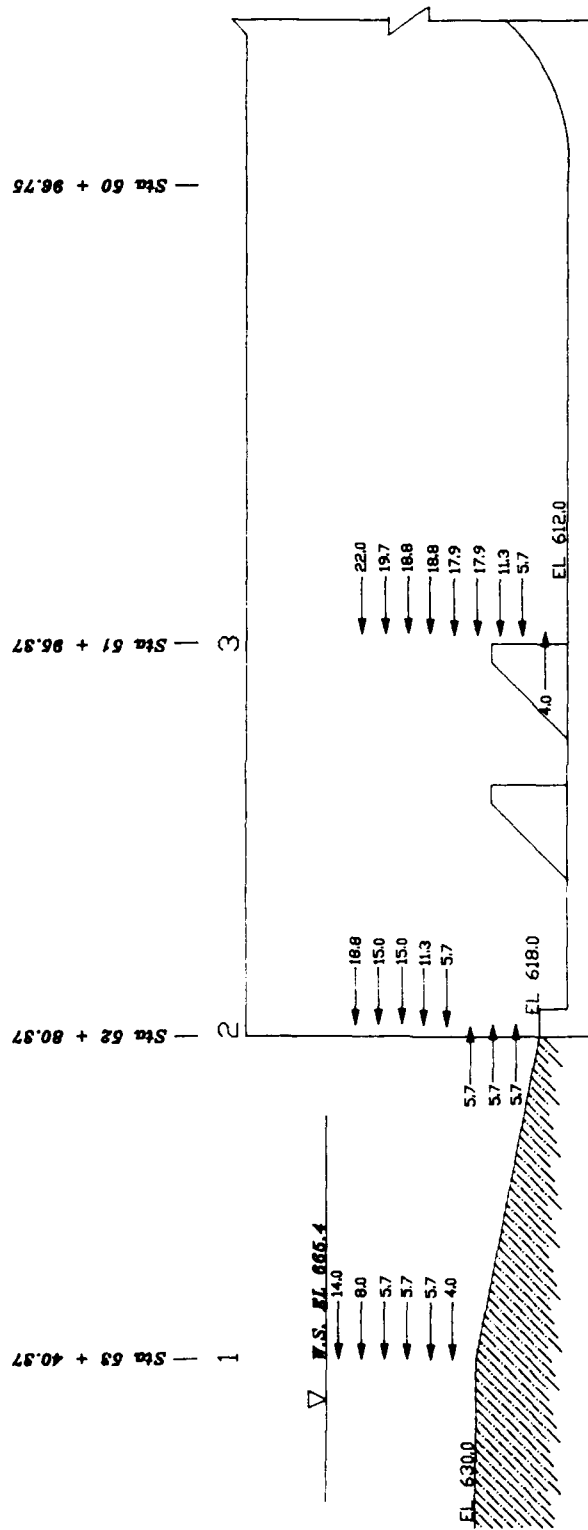
NOTE: VELOCITIES IN FEET PER SECOND AND IN  
5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



**VELOCITY AND FLOW PATTERNS**  
 STATION 9  
 SPILLWAY DISCHARGE 32,000 CFS  
 POWERHOUSE DISCHARGE 29,000 CFS  
 POOL EL 736.7  
 TAILWATER EL 664.5

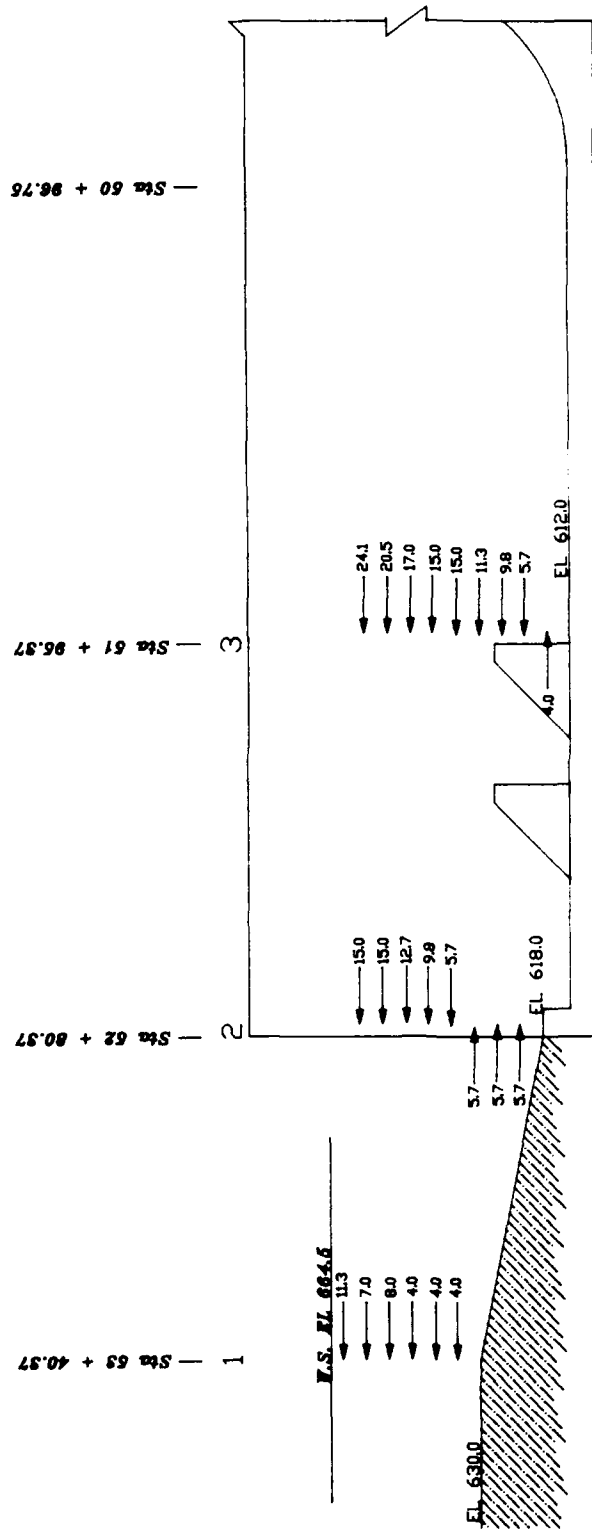
NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM

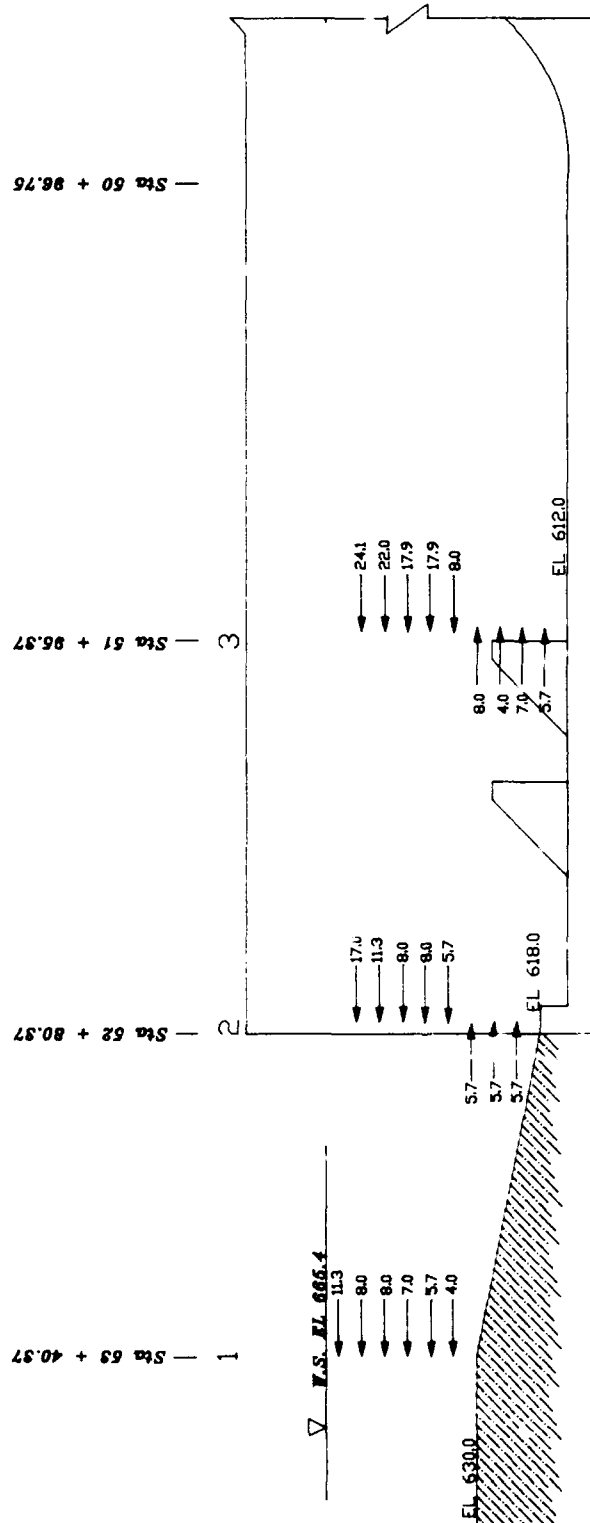




**VELOCITY AND FLOW PATTERNS**  
 STATION 1  
 SPILLWAY DISCHARGE 47,000 CFS  
 POWERHOUSE DISCHARGE 29,000 CFS  
 POOL EL 736.7  
 TAILWATER EL 665.4

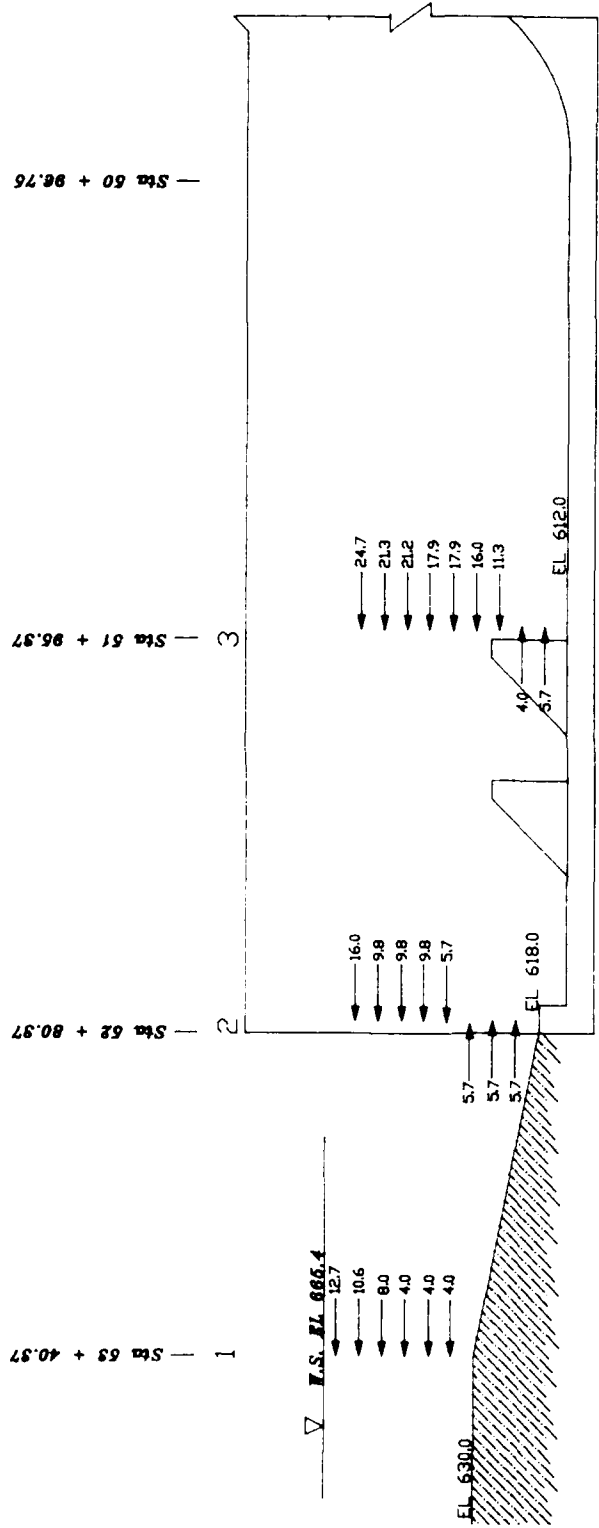
NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM





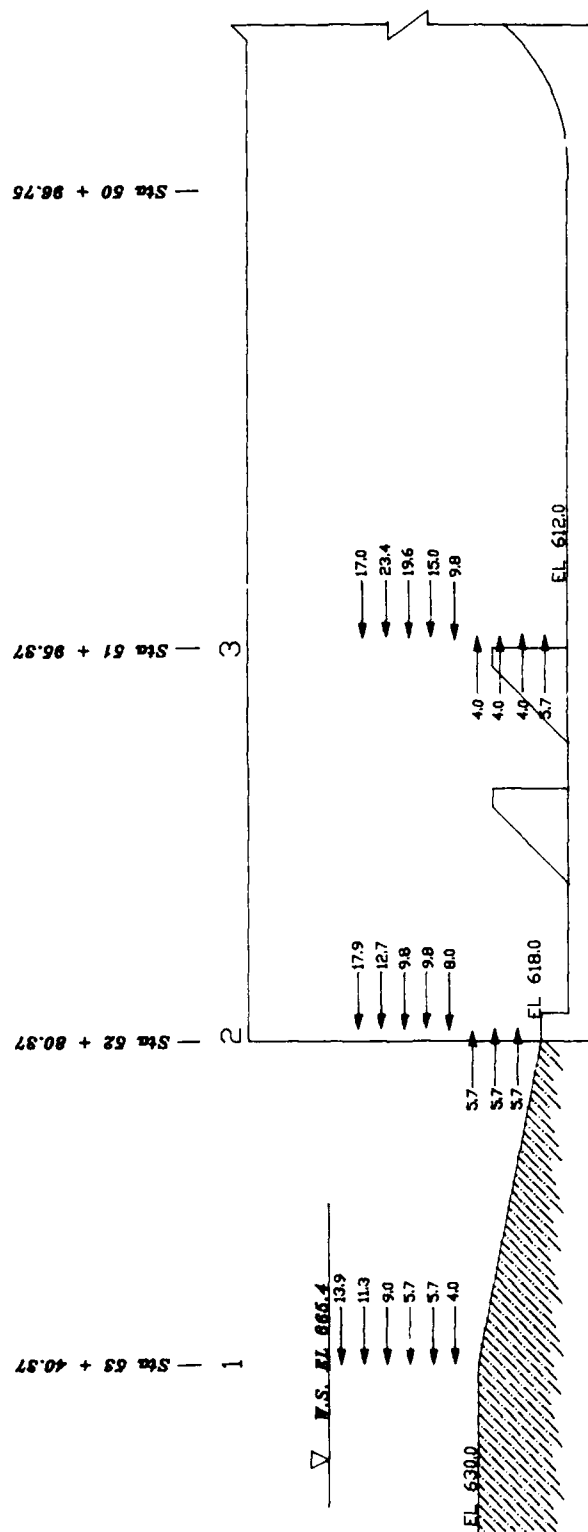
**VELOCITY AND FLOW PATTERNS**  
 STATION 3  
 SPILLWAY DISCHARGE 47,000 CFS  
 POWERHOUSE DISCHARGE 29,000 CFS  
 POOL EL 736.7  
 TAILWATER EL 665.4

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



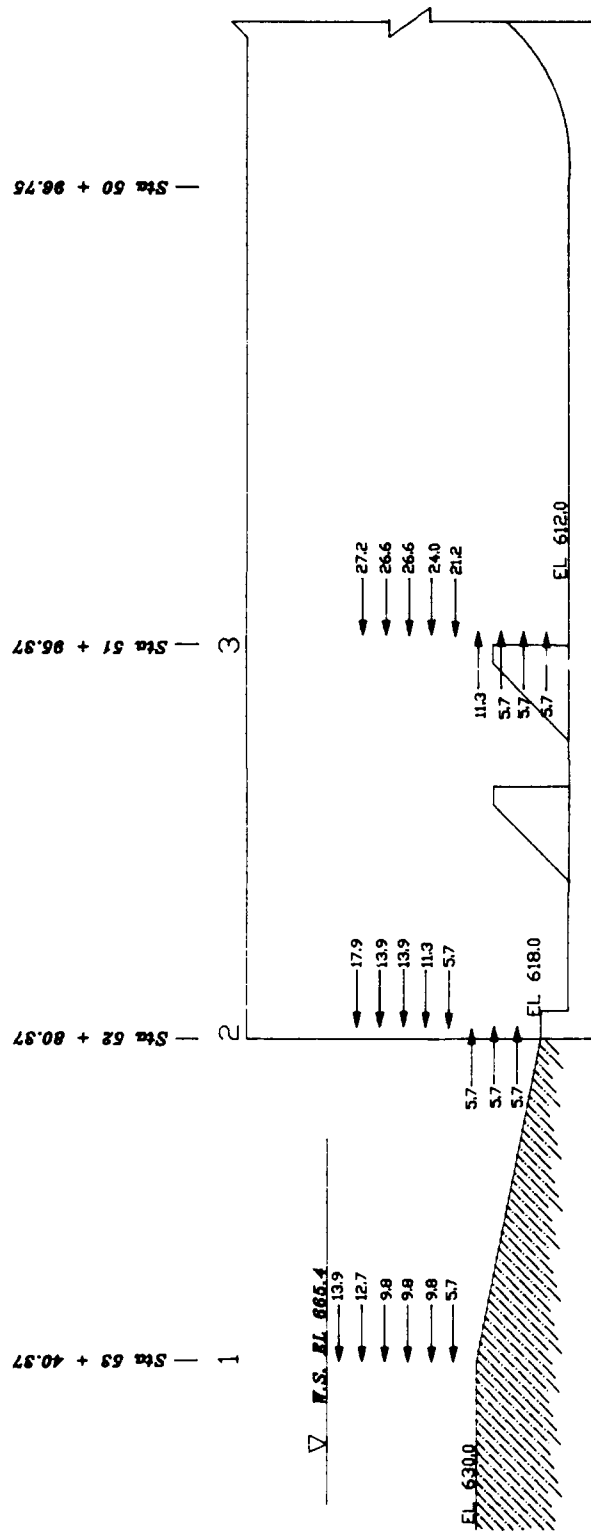
**VELOCITY AND FLOW PATTERNS**  
 STATION 4  
 SPILLWAY DISCHARGE 47,000 CFS  
 POWERHOUSE DISCHARGE 29,000 CFS  
 POOL EL 736.7  
 TAILWATER EL 665.4

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



NOTE: VELOCITIES IN FEET PER SECOND AND IN  
5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM





**VELOCITY AND FLOW PATTERNS**  
 STATION 6  
 SPILLWAY DISCHARGE 47,000 CFS  
 POWERHOUSE DISCHARGE 29,000 CFS  
 POOL EL 736.7  
 TAILWATER EL 665.4

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM

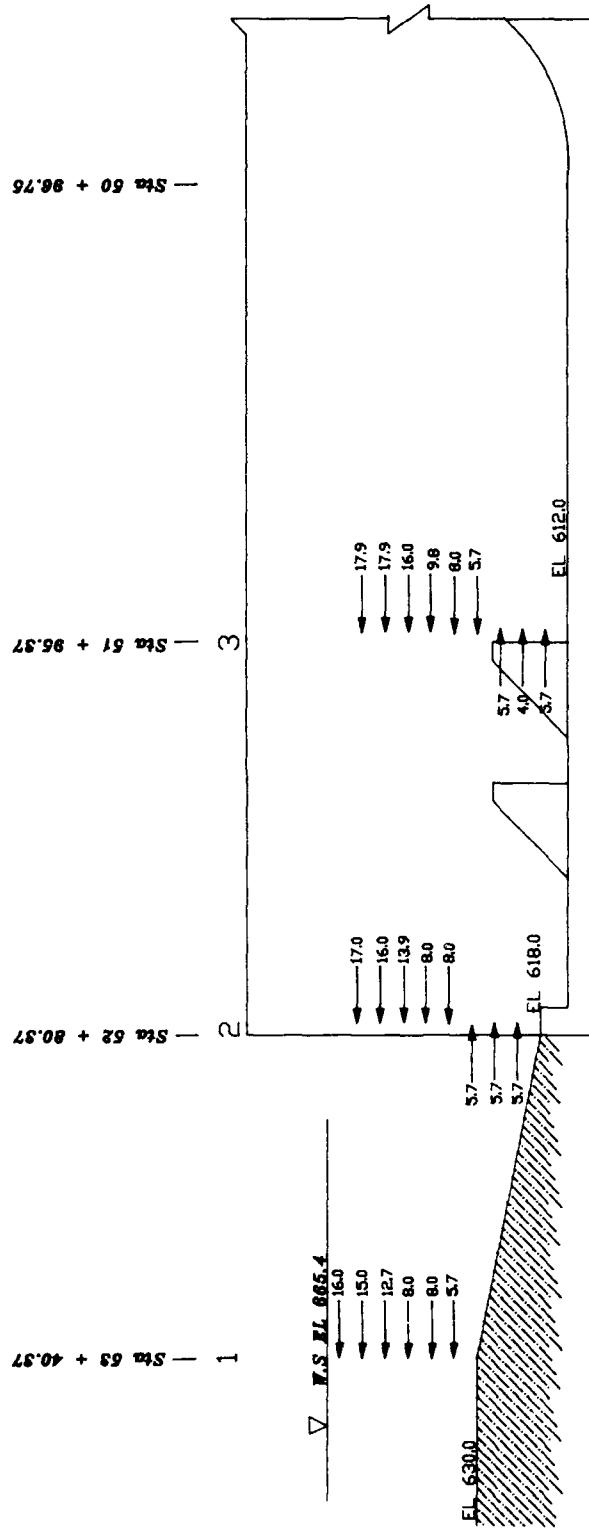
## STATION 7

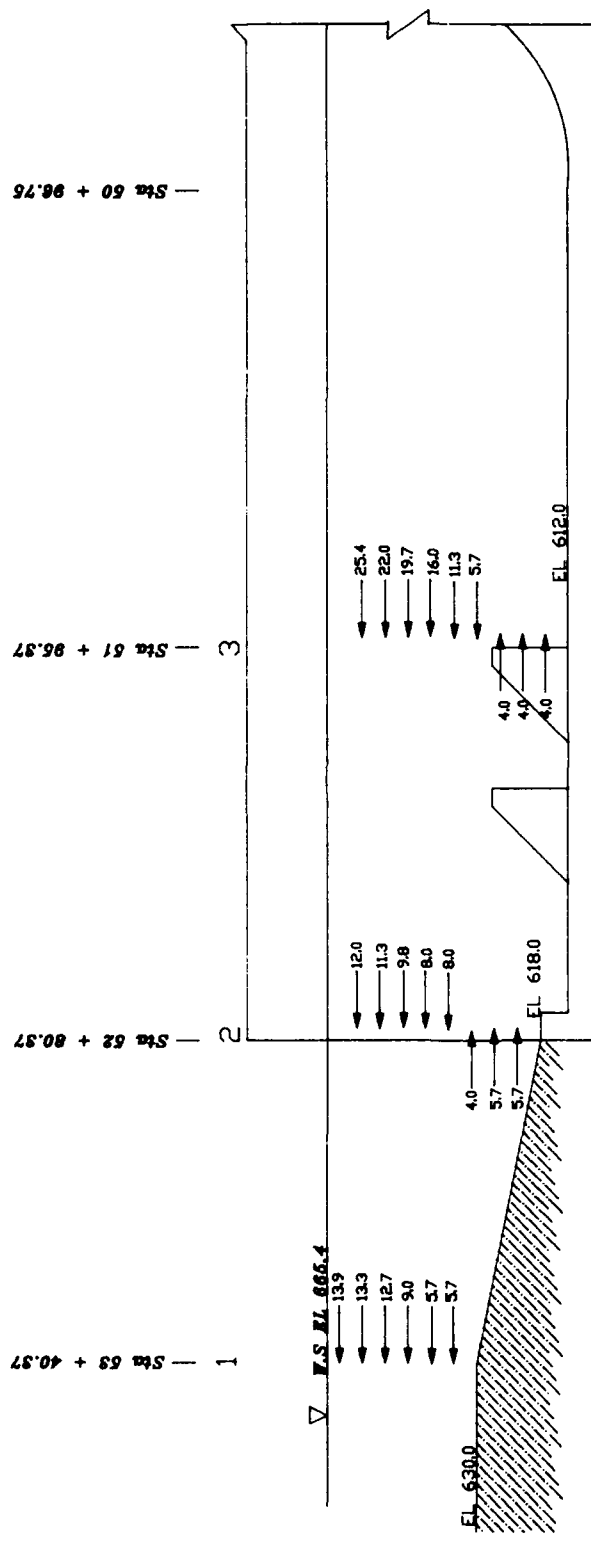
POWERHOUSE DISCHARGE 29,000 CFS

POOL EL 736.7

TAILWATER EL 665.4

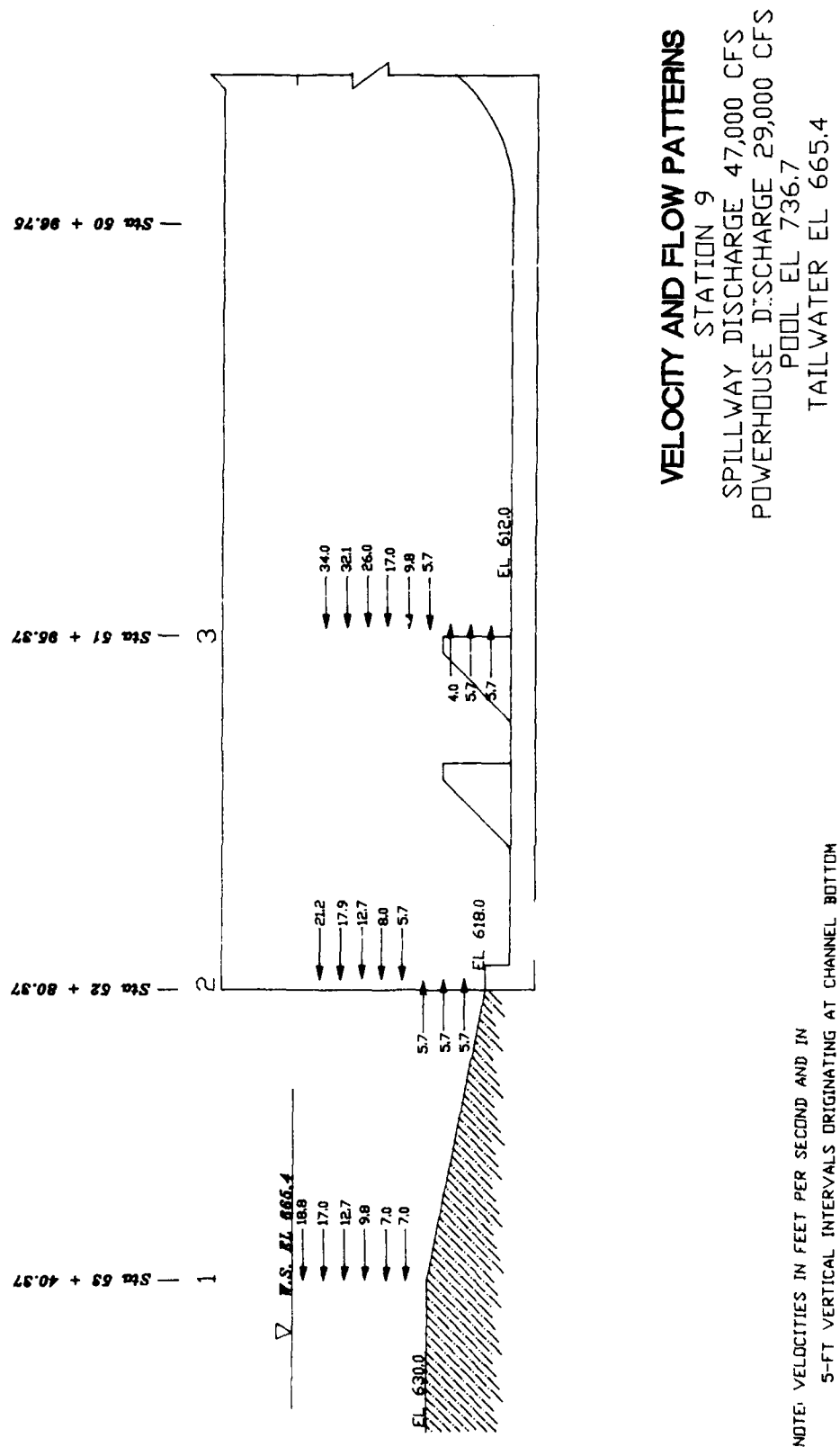
NOTE: VELOCITIES IN FEET PER SECOND AND IN 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM

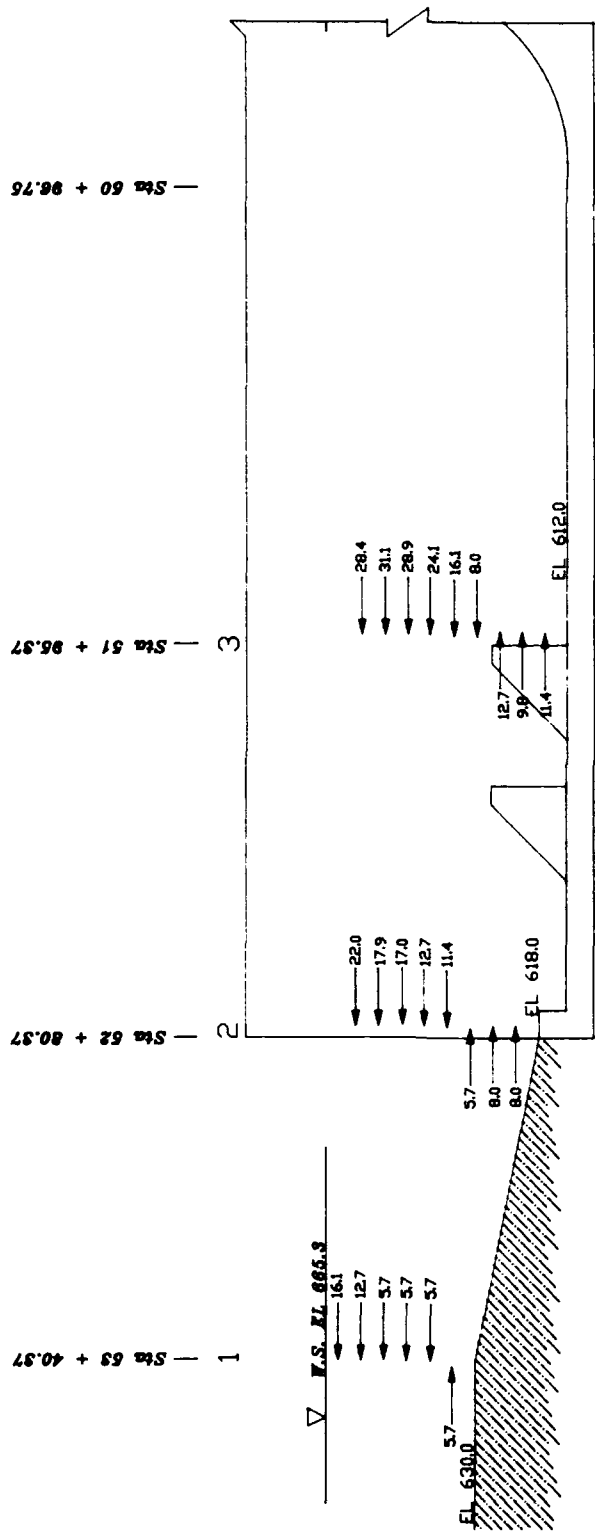




**VELOCITY AND FLOW PATTERNS**  
 STATION 8  
 SPILLWAY DISCHARGE 47,000 CFS  
 POWERHOUSE DISCHARGE 29,000 CFS  
 POOL EL 736.7  
 TAILWATER EL 665.4

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM





# VELOCITY AND FLOW PATTERNS

STATION 1

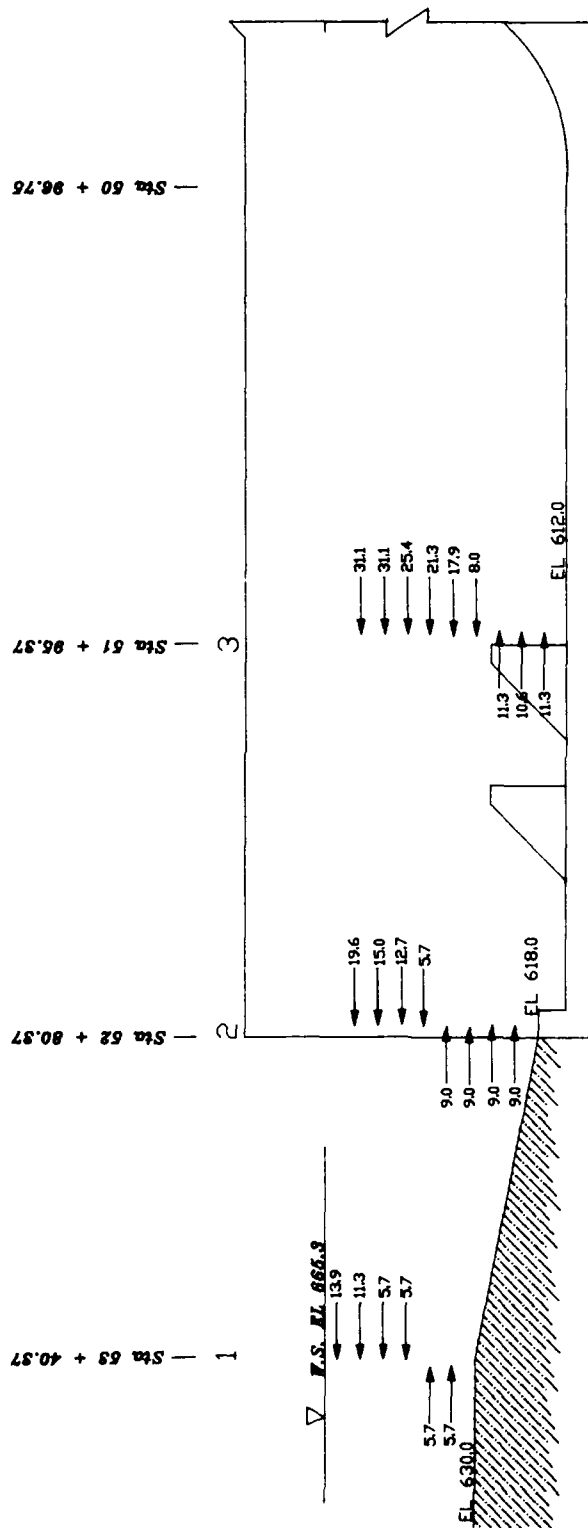
SPILLWAY DISCHARGE 49,000 CFS

POWERHOUSE DISCHARGE 29,000 CFS

POOL EL 738.7

TAILWATER EL 665.3

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



**VELOCITY AND FLOW PATTERNS**  
 STATION 2  
 SPILLWAY DISCHARGE 49,000 CFS  
 POWERHOUSE DISCHARGE 29,000 CFS  
 POOL EL 738.7  
 TAILWATER EL 665.3

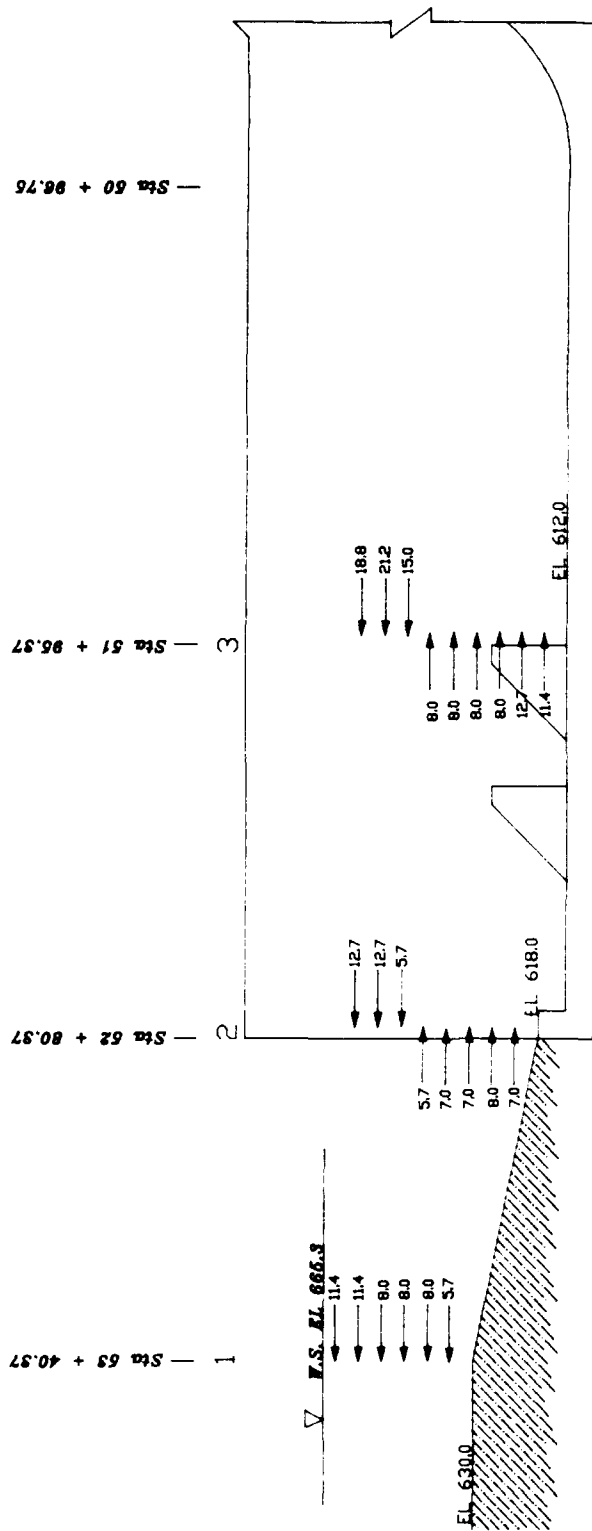
NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



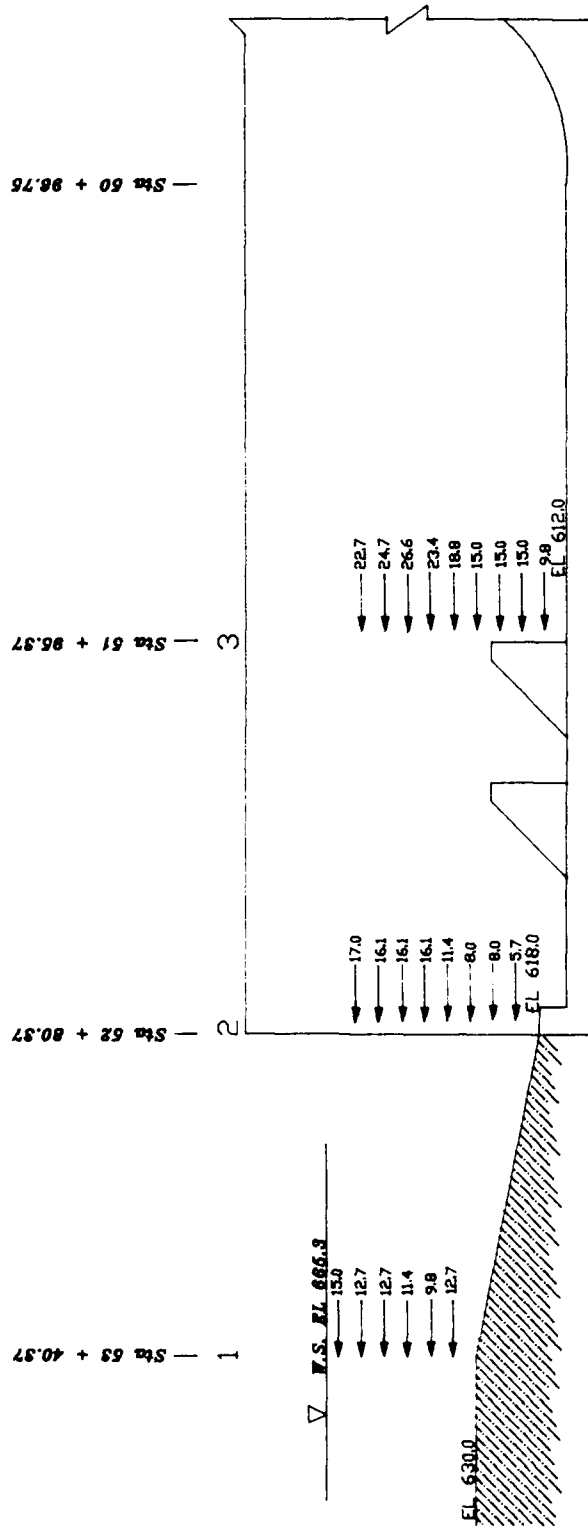
STATION 4  
SPILLWAY DISCHARGE 49,000 CFS  
POWERHOUSE DISCHARGE 29,000 CFS  
POOL EL 738.7  
TAILWATER EL 665.3

NOTE: VELOCITIES IN FEET PER SECOND AND IN 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



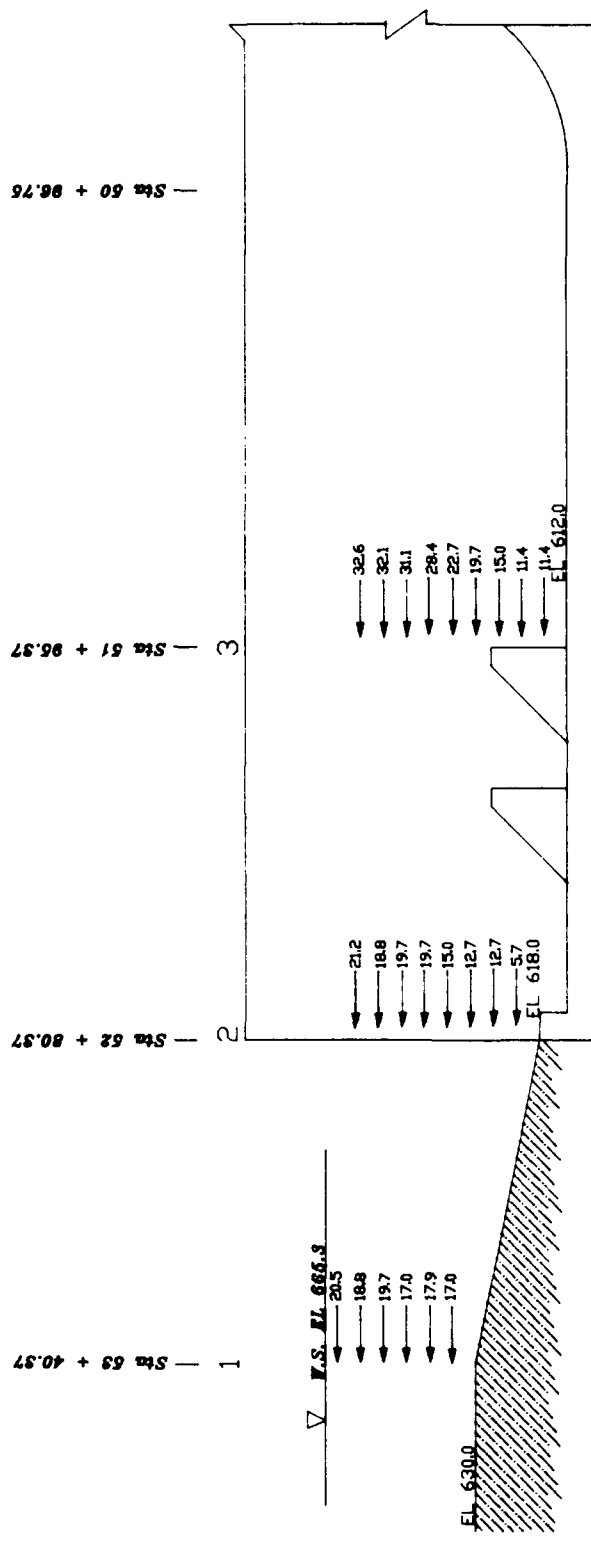


NOTE: VELOCITIES IN FEET PER SECOND AND IN  
5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



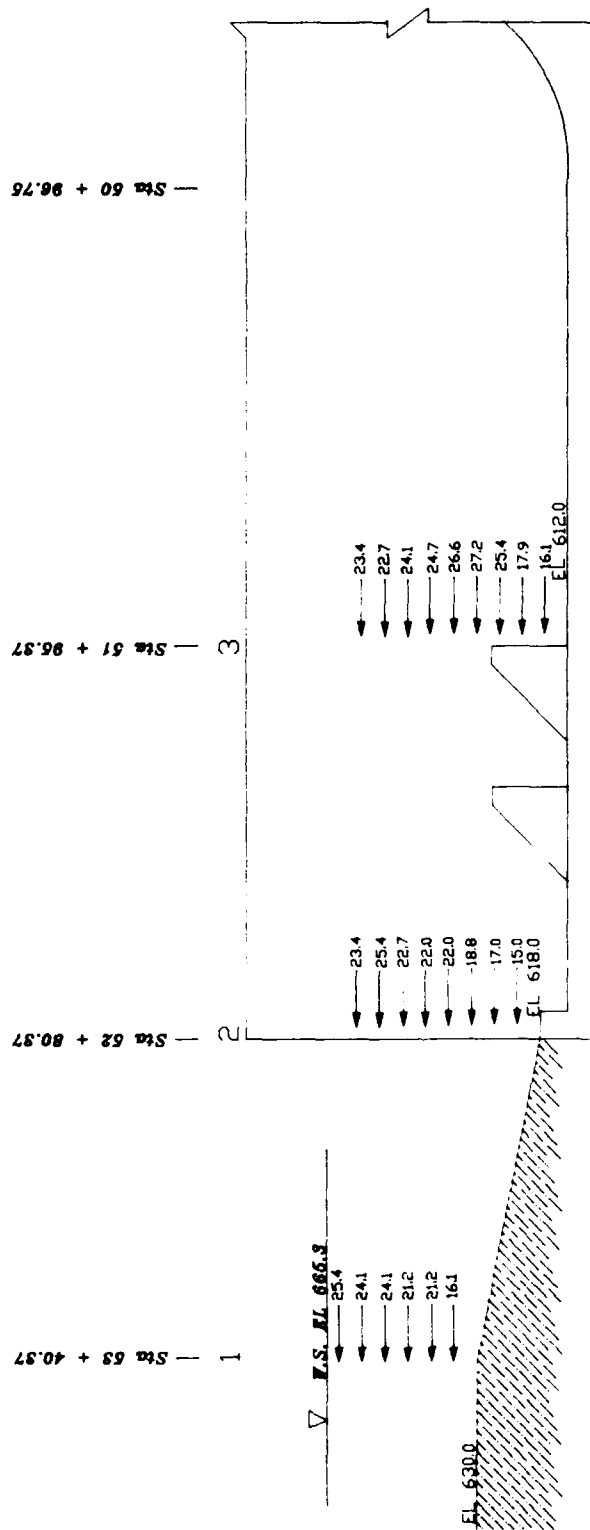
**VELOCITY AND FLOW PATTERNS**  
 STATION 6  
 SPILLWAY DISCHARGE 49,000 CFS  
 POWERHOUSE DISCHARGE 29,000 CFS  
 POOL EL 738.7  
 TAILWATER EL 665.3

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



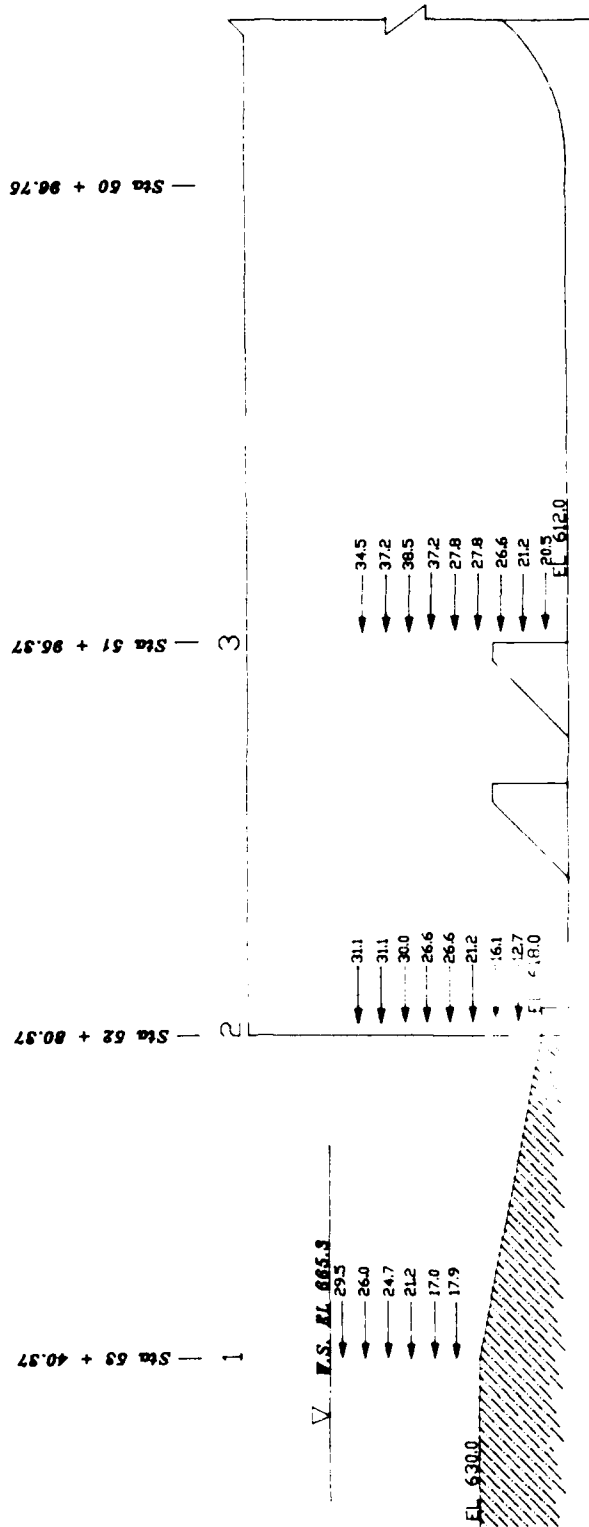
**VELOCITY AND FLOW PATTERNS**  
 STATION 7  
 SPILLWAY DISCHARGE 49,000 CFS  
 POWERHOUSE DISCHARGE 29,000 CFS  
 POOL EL 738.7  
 TAILWATER EL 665.3

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



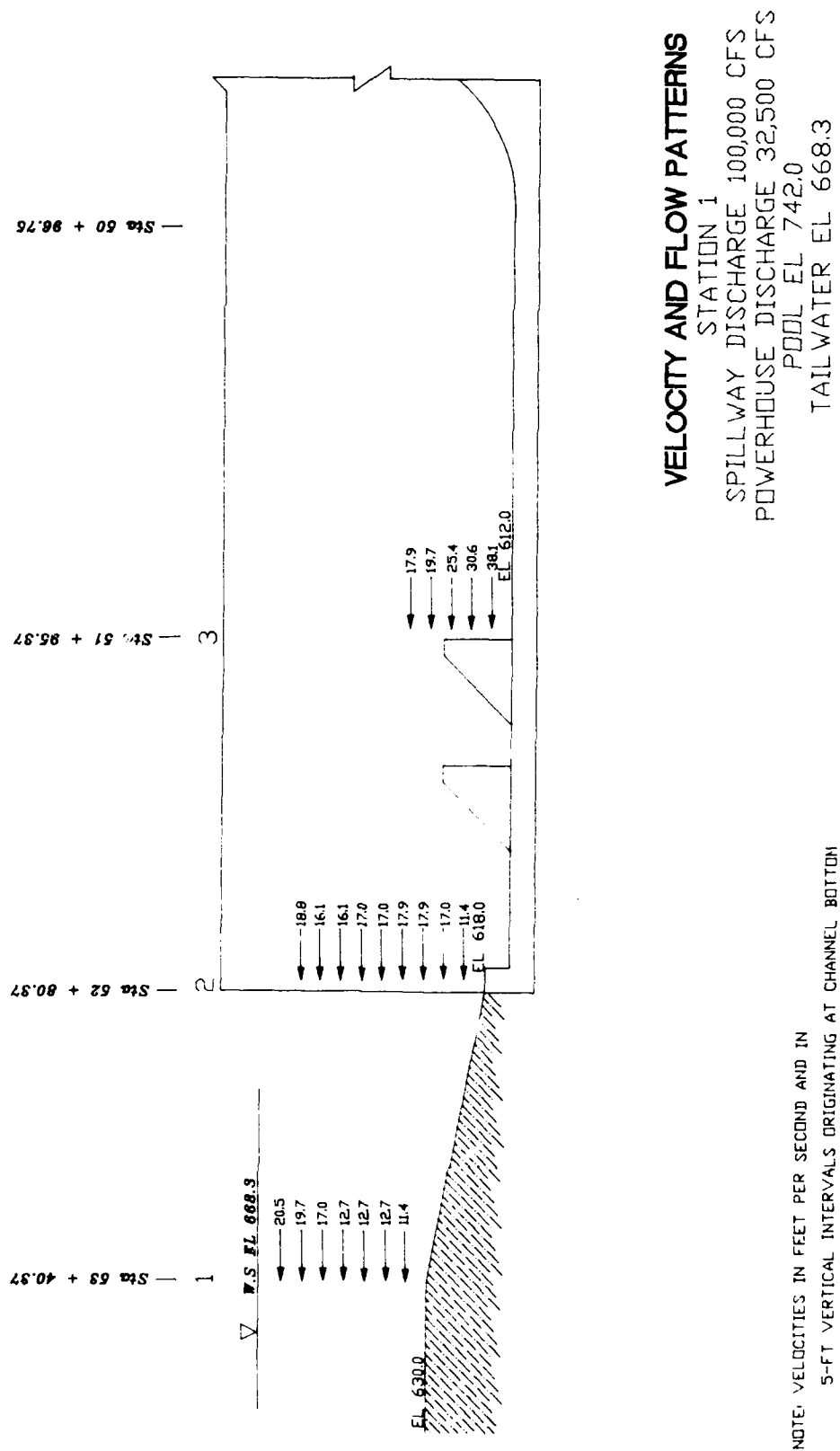
**VELOCITY AND FLOW PATTERNS**  
 STATION 8  
 SPILLWAY DISCHARGE 49,000 CFS  
 POWERHOUSE DISCHARGE 29,000 CFS  
 POOL EL 738.7  
 TAILWATER EL 665.3

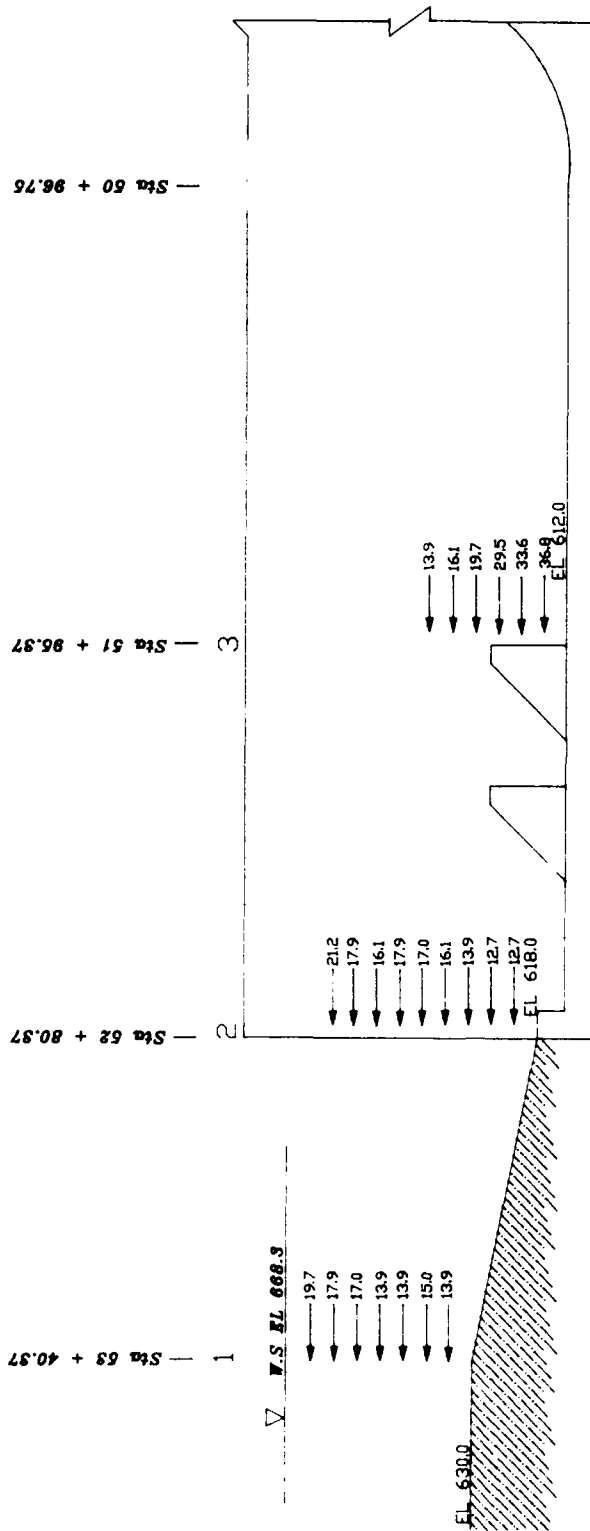
NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



**VELOCITY AND FLOW PATTERNS**  
 STATION 9  
 SPILLWAY DISCHARGE 49,000 CFS  
 POWERHOUSE DISCHARGE 29,000 CFS  
 POOL EL 738.7  
 TAILWATER EL 665.3

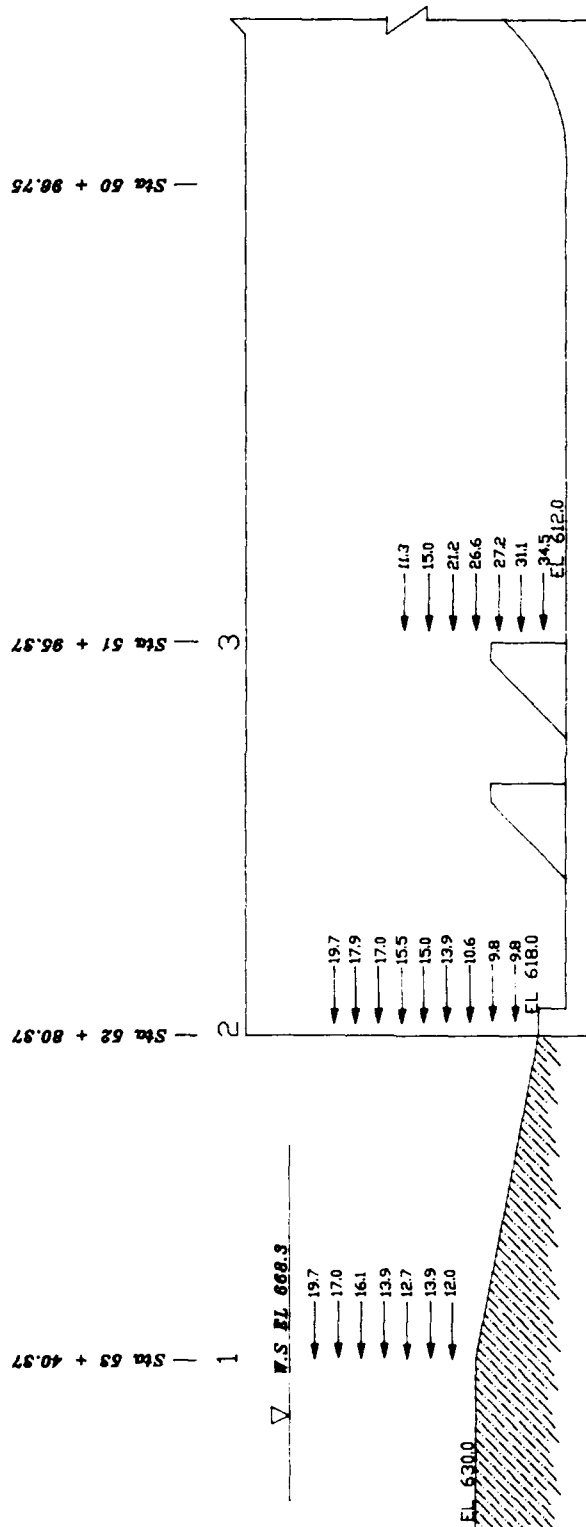
NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM





**VELOCITY AND FLOW PATTERNS**  
 STATION 2  
 SPILLWAY DISCHARGE 100,000 CFS  
 POWERHOUSE DISCHARGE 32,500 CFS  
 POOL EL 742.0  
 TAILWATER EL 668.3

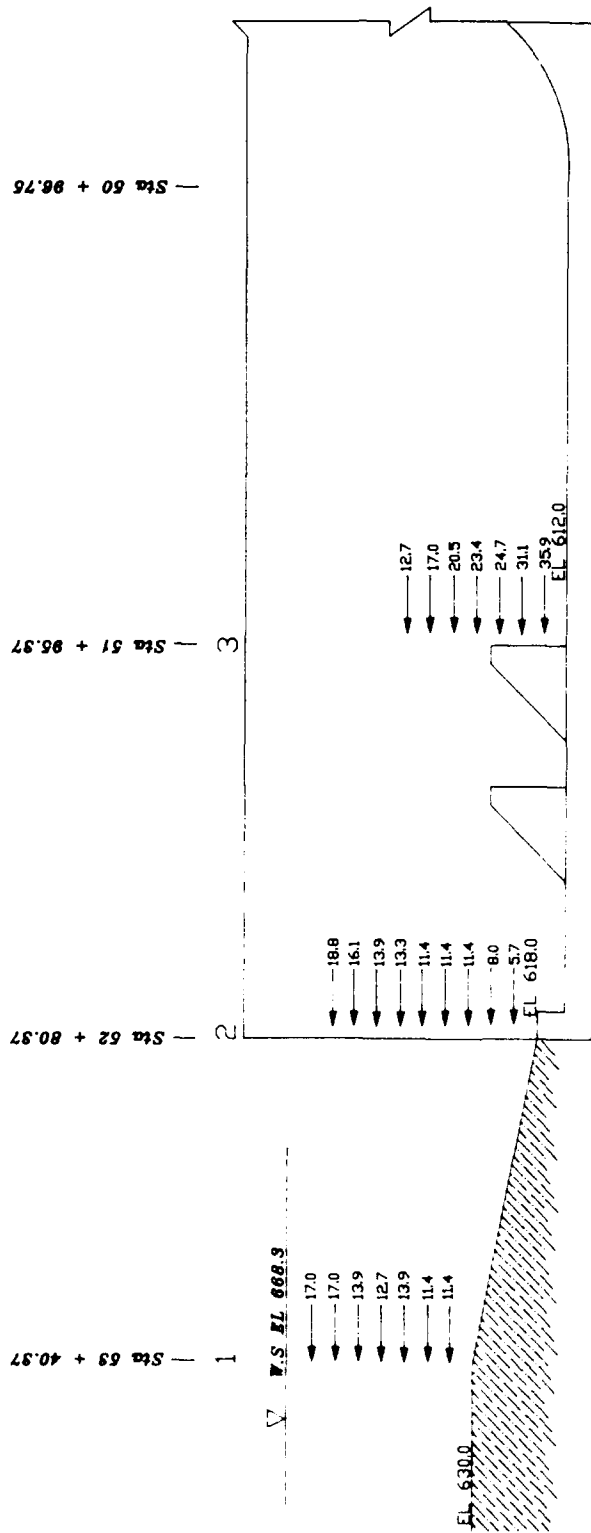
NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



**VELOCITY AND FLOW PATTERNS**  
 STATION 3  
 SPILLWAY DISCHARGE 100,000 CFS  
 POWERHOUSE DISCHARGE 32,500 CFS  
 POOL EL 742.0  
 TAILWATER EL 668.3

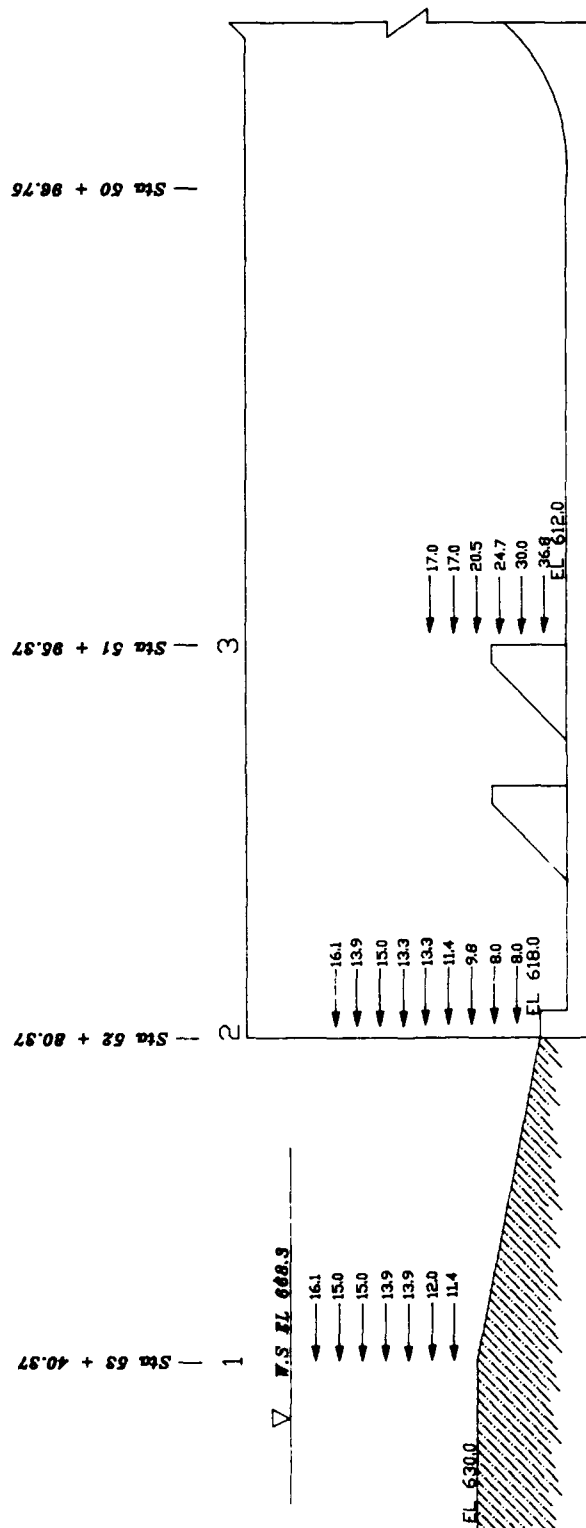
NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM





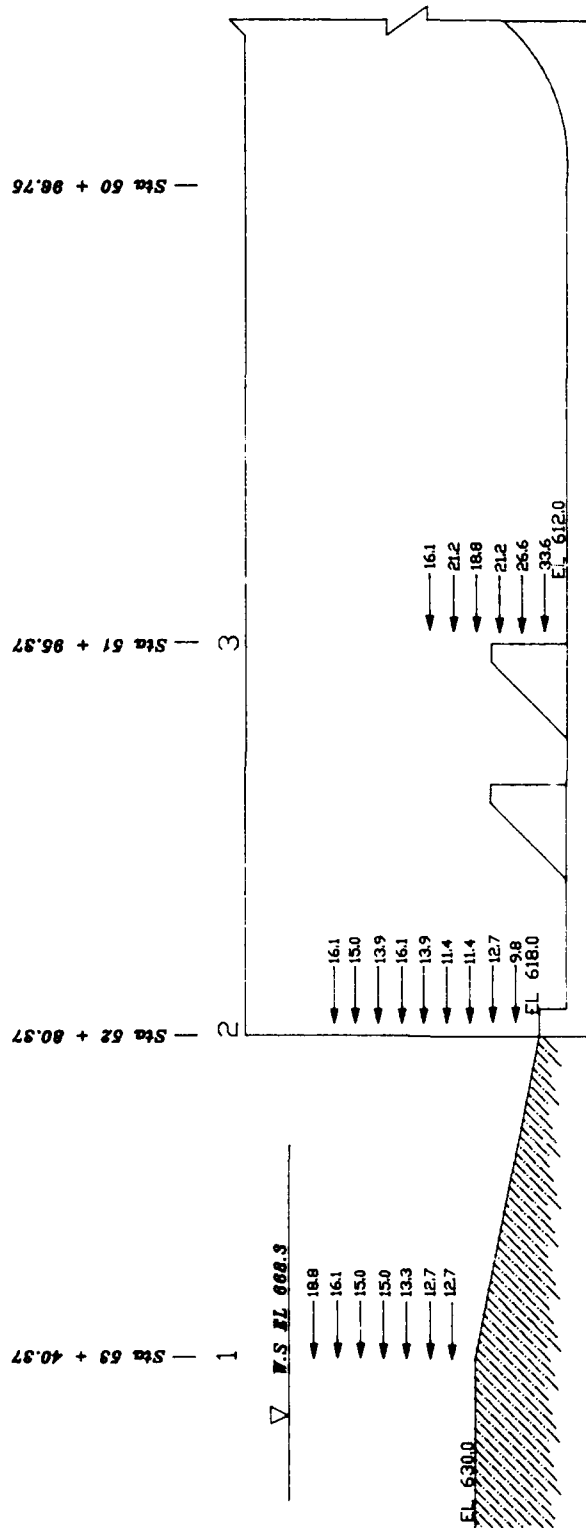
**VELOCITY AND FLOW PATTERNS**  
 STATION 4  
 SPILLWAY DISCHARGE 100,000 CFS  
 POWERHOUSE DISCHARGE 32,500 CFS  
 POOL EL 742.0  
 TAILWATER EL 668.3

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



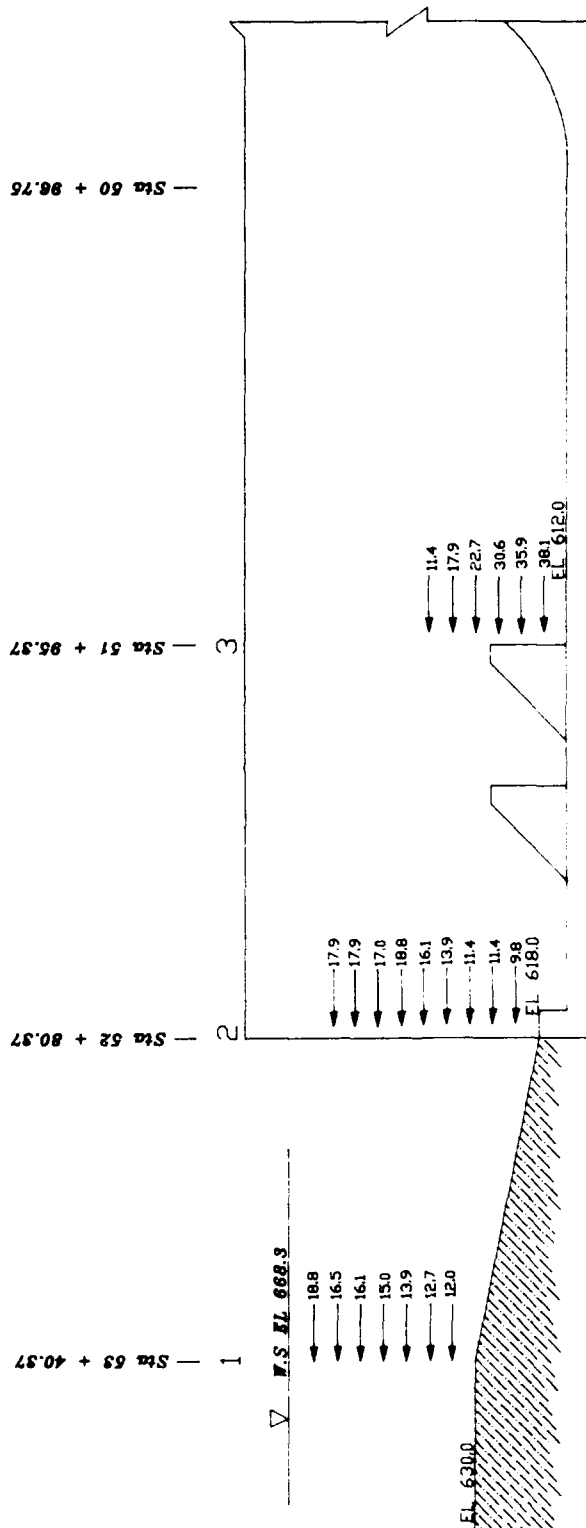
**VELOCITY AND FLOW PATTERNS**  
 STATION 5  
 SPILLWAY DISCHARGE 100,000 CFS  
 POWERHOUSE DISCHARGE 32,500 CFS  
 POOL EL 742.0  
 TAILWATER EL 668.3

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



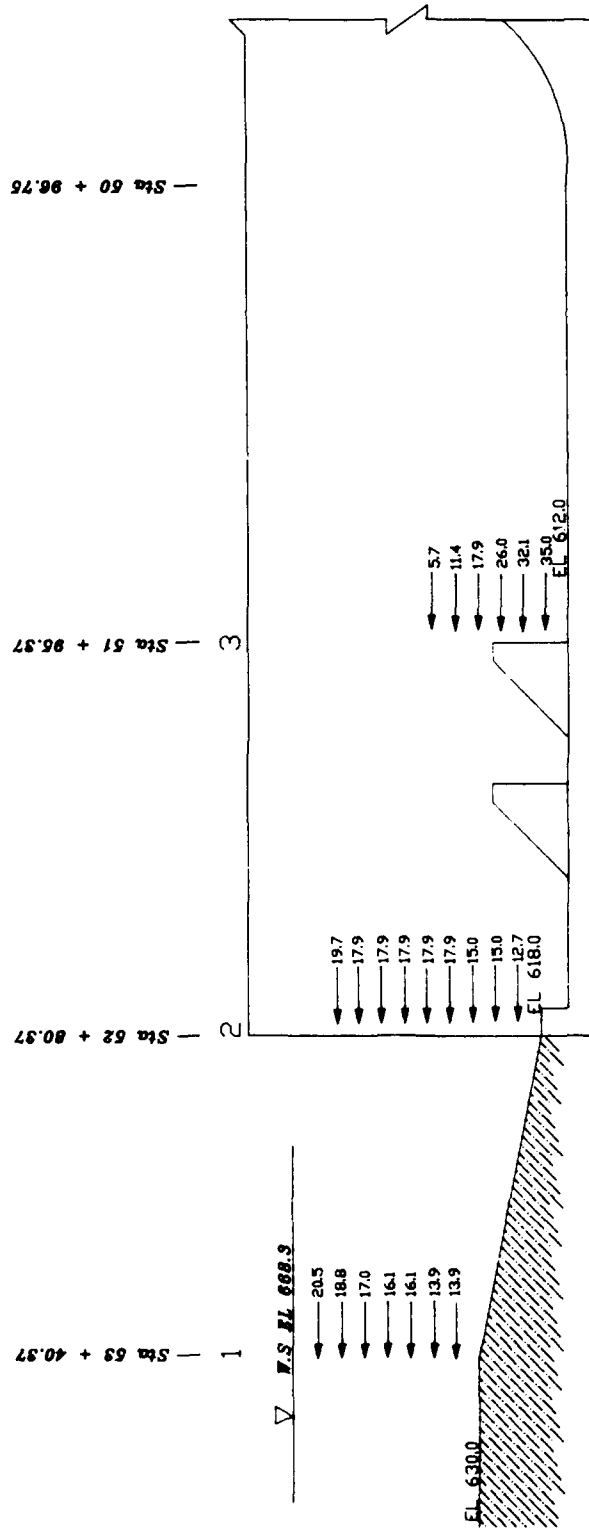
**VELOCITY AND FLOW PATTERNS**  
 STATION 6  
 SPILLWAY DISCHARGE 100,000 CFS  
 POWERHOUSE DISCHARGE 32,500 CFS  
 POOL EL 742.0  
 TAILWATER EL 668.3

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



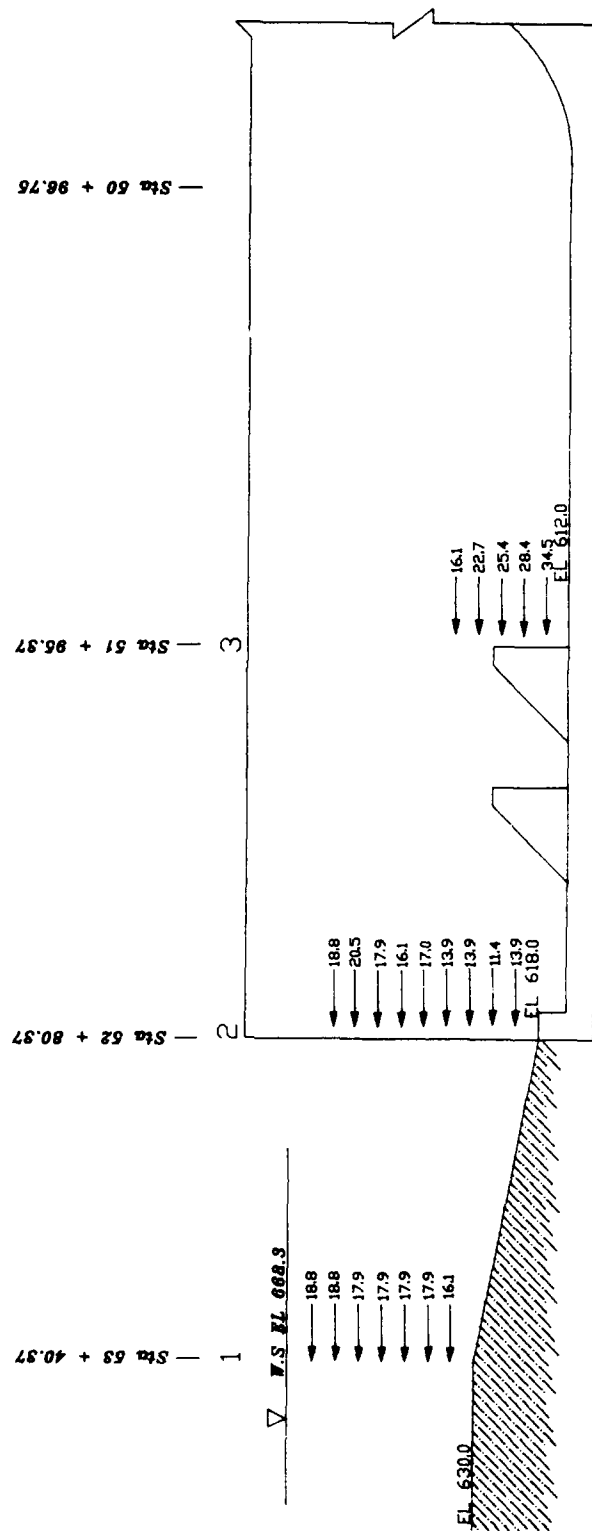
**VELOCITY AND FLOW PATTERNS**  
 STATION 7  
 SPILLWAY DISCHARGE 100,000 CFS  
 POWERHOUSE DISCHARGE 32,500 CFS  
 POOL EL 742.0  
 TAILWATER EL 668.3

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



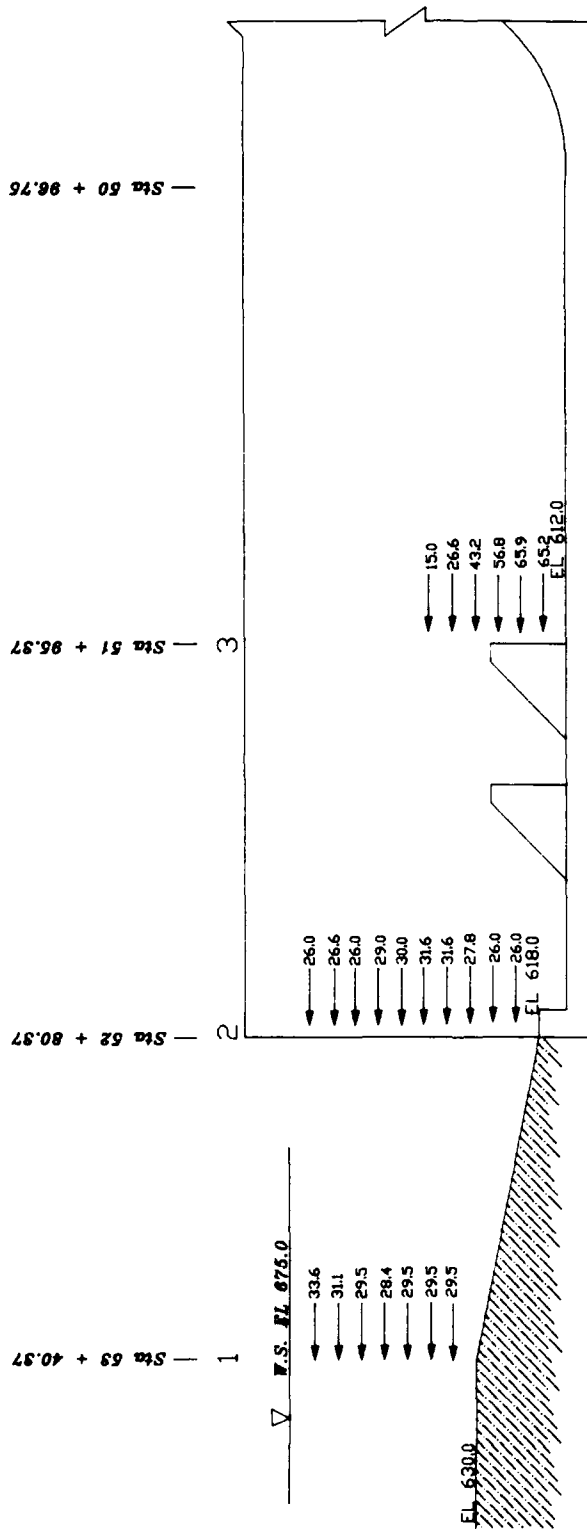
**VELOCITY AND FLOW PATTERNS**  
 STATION 8  
 SPILLWAY DISCHARGE 100,000 CFS  
 POWERHOUSE DISCHARGE 32,500 CFS  
 POOL EL 742.0  
 TAILWATER EL 668.3

NOTE VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



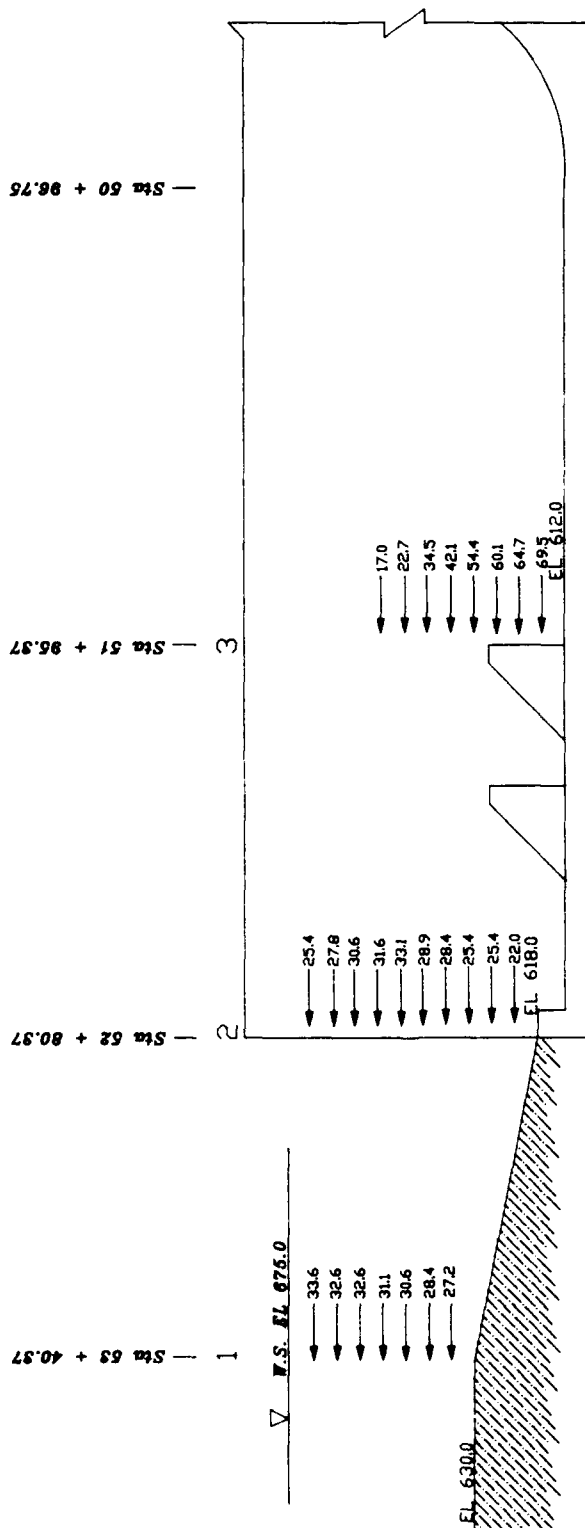
**VELOCITY AND FLOW PATTERNS**  
 STATION 9  
 SPILLWAY DISCHARGE 100,000 CFS  
 POWERHOUSE DISCHARGE 32,500 CFS  
 POOL EL 742.0  
 TAILWATER EL 668.3

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



**VELOCITY AND FLOW PATTERNS**  
 STATION 1  
 SPILLWAY DISCHARGE 229,000 CFS  
 POWERHOUSE CLOSED  
 POOL EL 742.0  
 TAILWATER EL 675

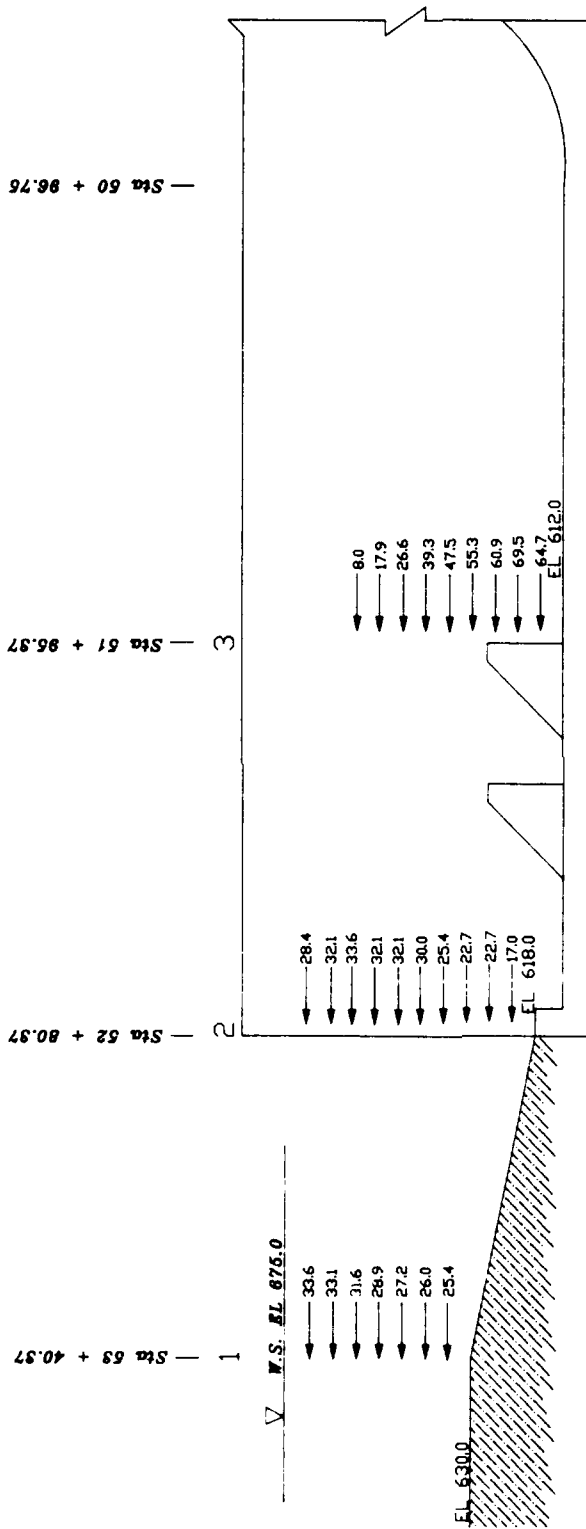
NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



**VELOCITY AND FLOW PATTERNS**  
 STATION 2  
 SPILLWAY DISCHARGE 229,000 CFS  
 POWERHOUSE CLOSED  
 POOL EL 742.0  
 TAILWATER EL 675

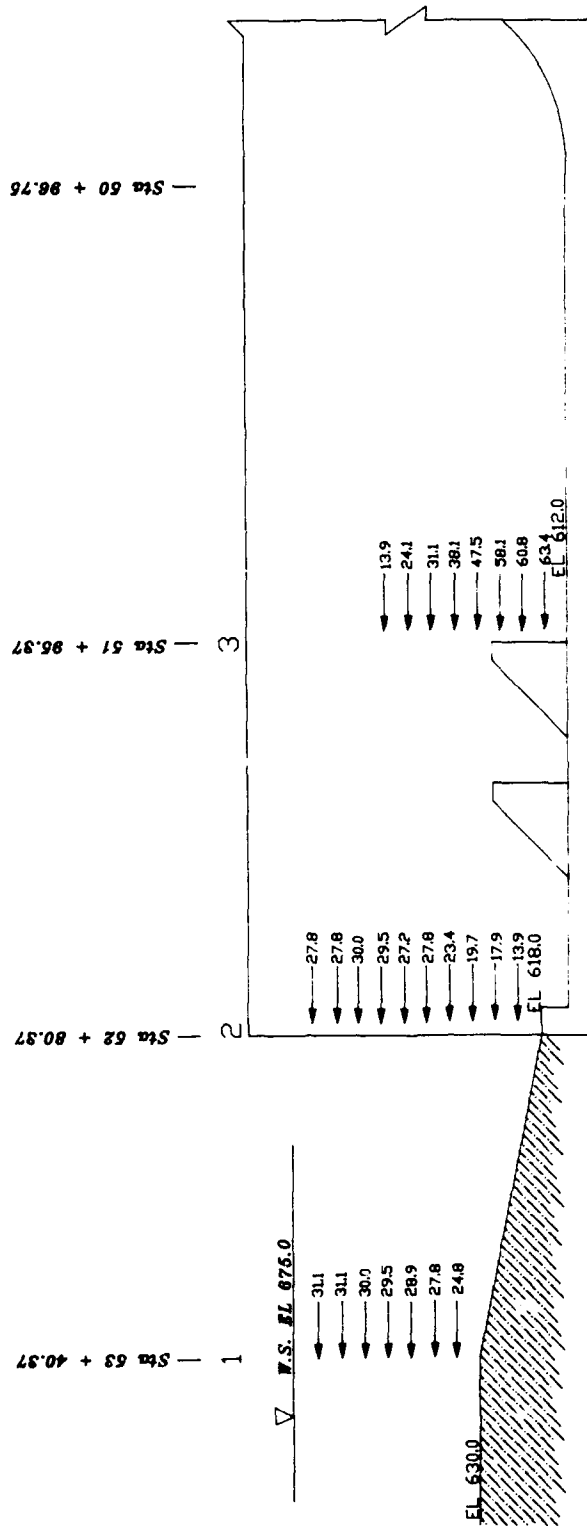
NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM





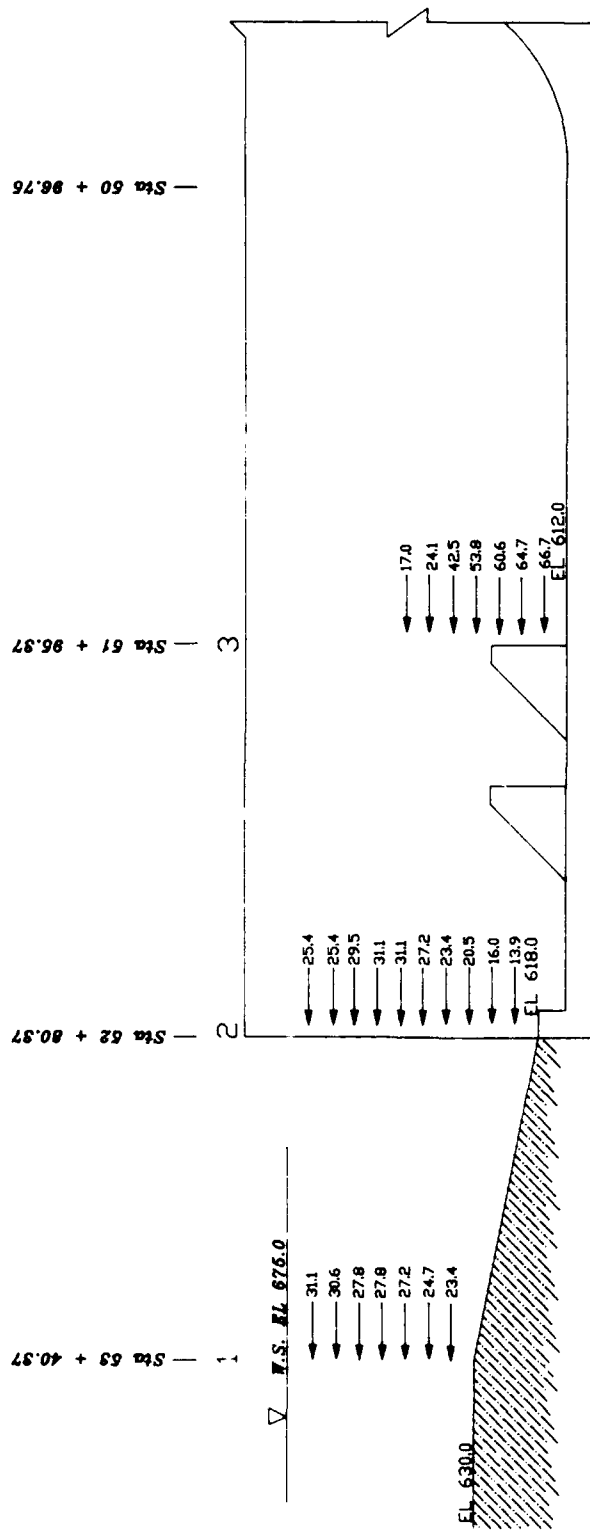
# VELOCITY AND FLOW PATTERNS STATION 3 SPILLWAY DISCHARGE 229,000 CFS POWERHOUSE CLOSED POOL EL 742.0 TAILWATER EL 675

NOTE: VELOCITIES IN FEET PER SECOND AND IN 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



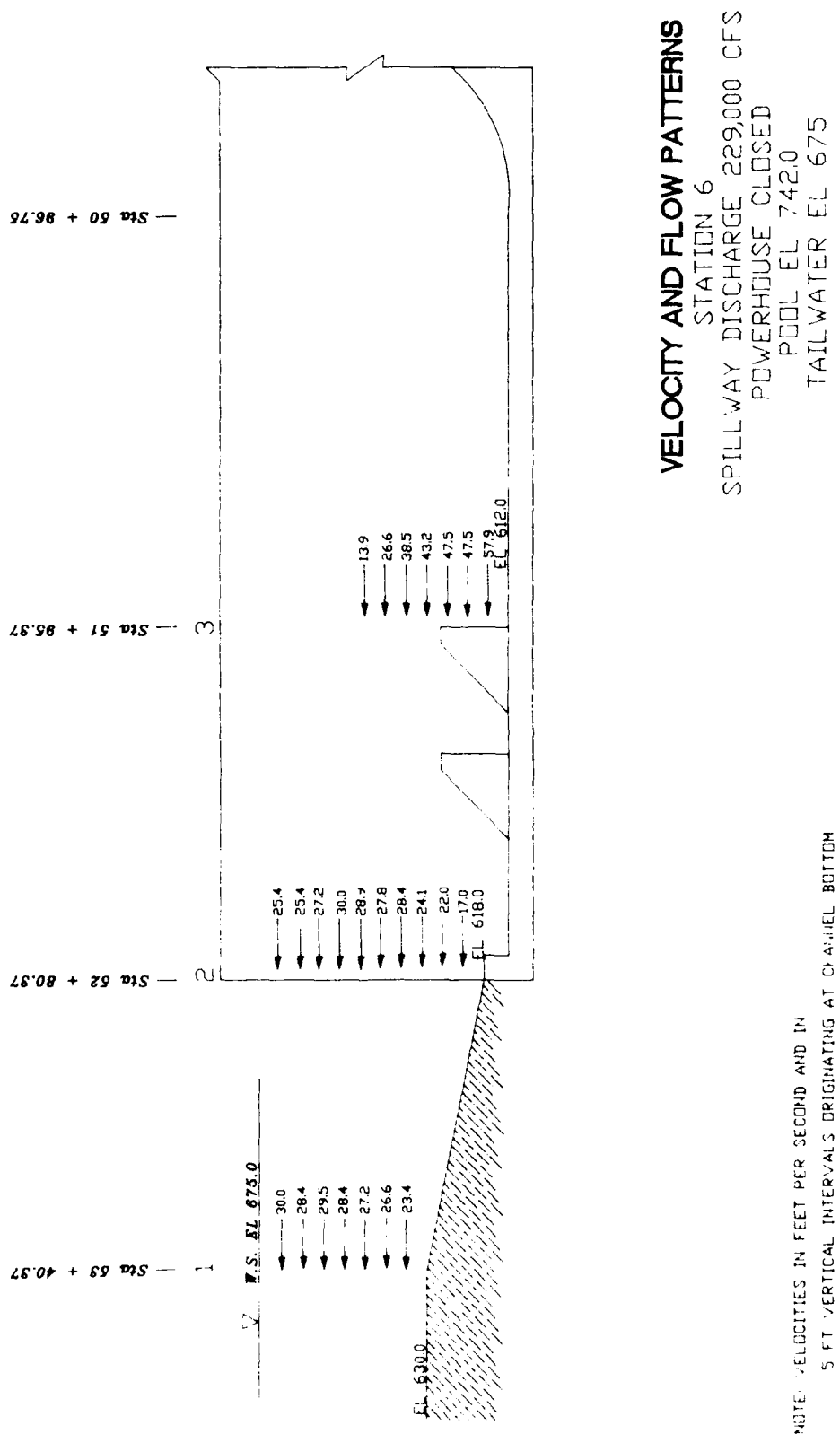
**VELOCITY AND FLOW PATTERNS**  
 STATION 4  
 SPILLWAY DISCHARGE 229,000 CFS  
 POWERHOUSE CLOSED  
 POOL EL 742.0  
 TAILWATER EL 675

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



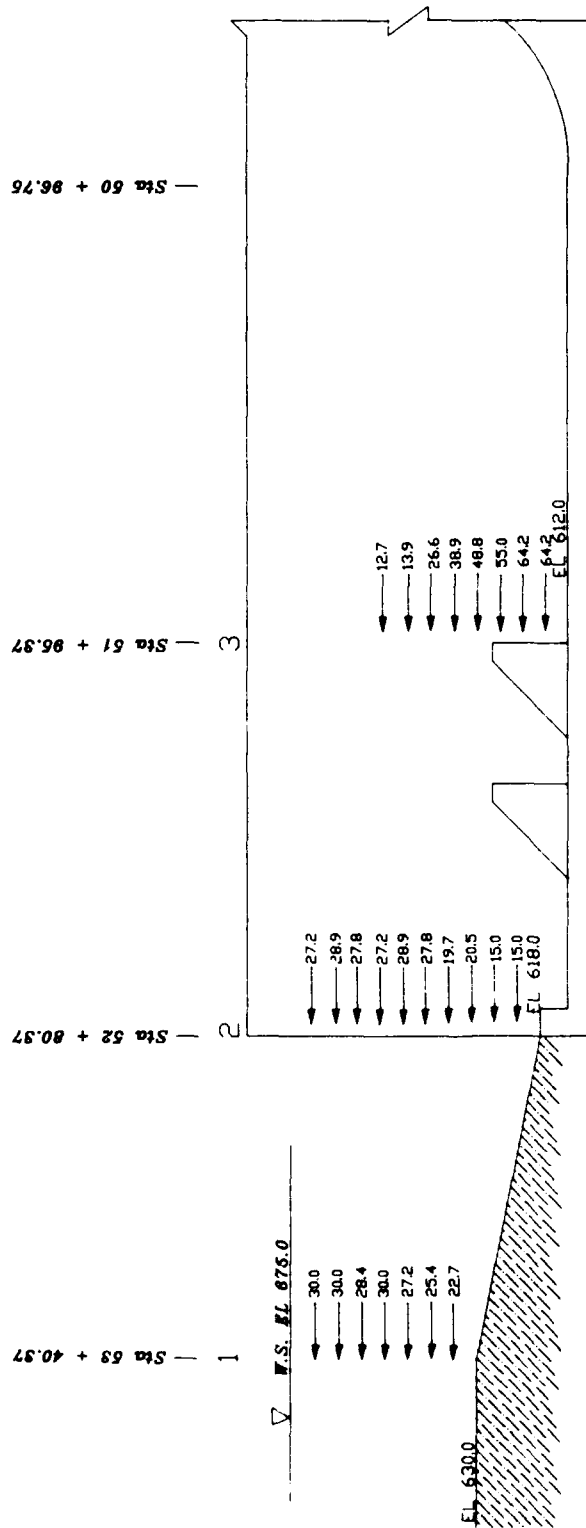
# **VELOCITY AND FLOW PATTERNS** **STATION 5** **SPILLWAY DISCHARGE 229,000 CFS** **POWERHOUSE CLOSED** **POOL EL 742.0** **TAILWATER EL 675**

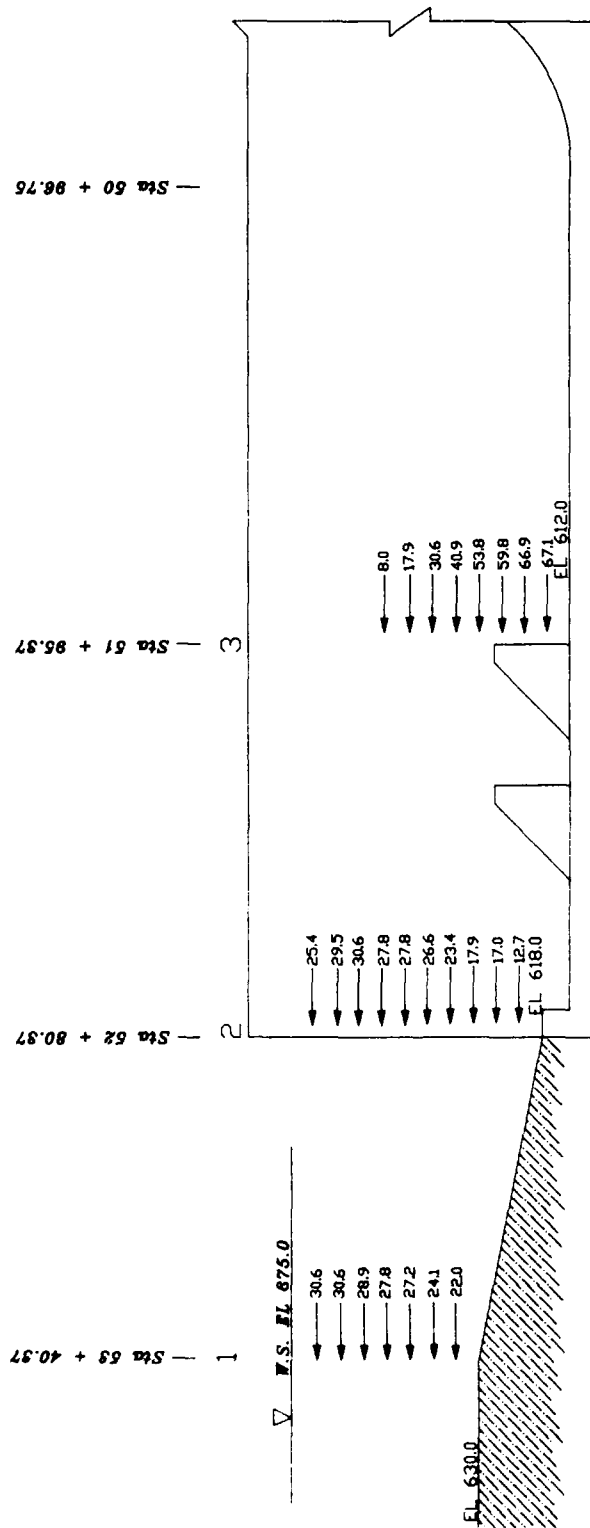
NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



TAILWATER EL 675

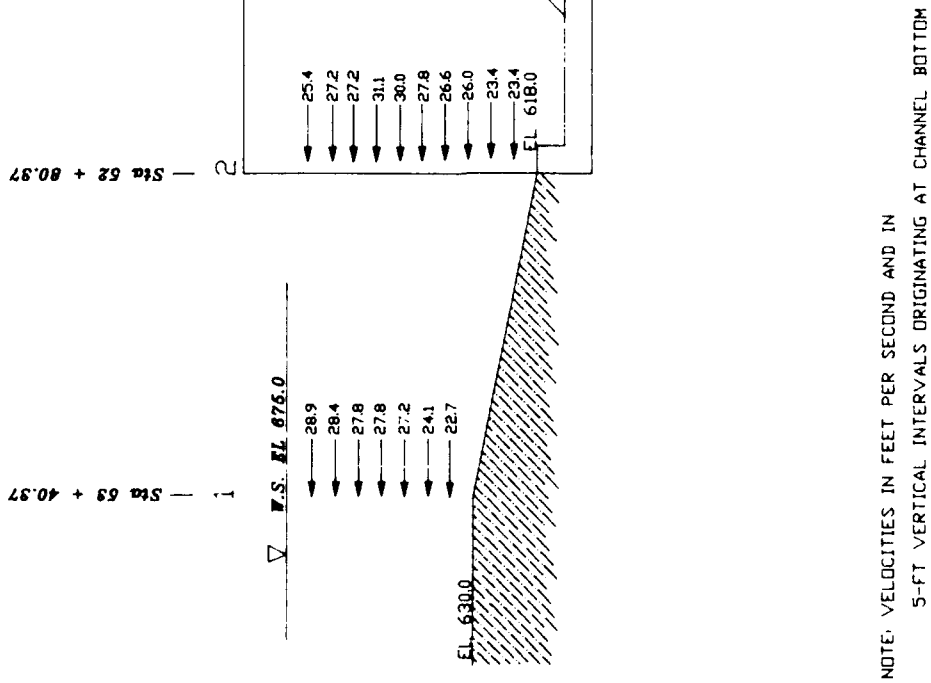
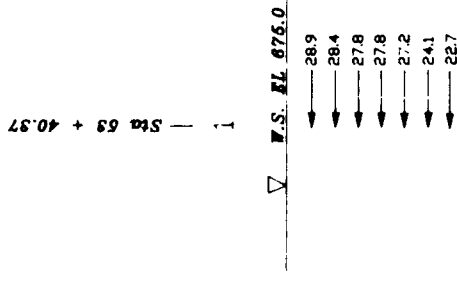
PLATE 49





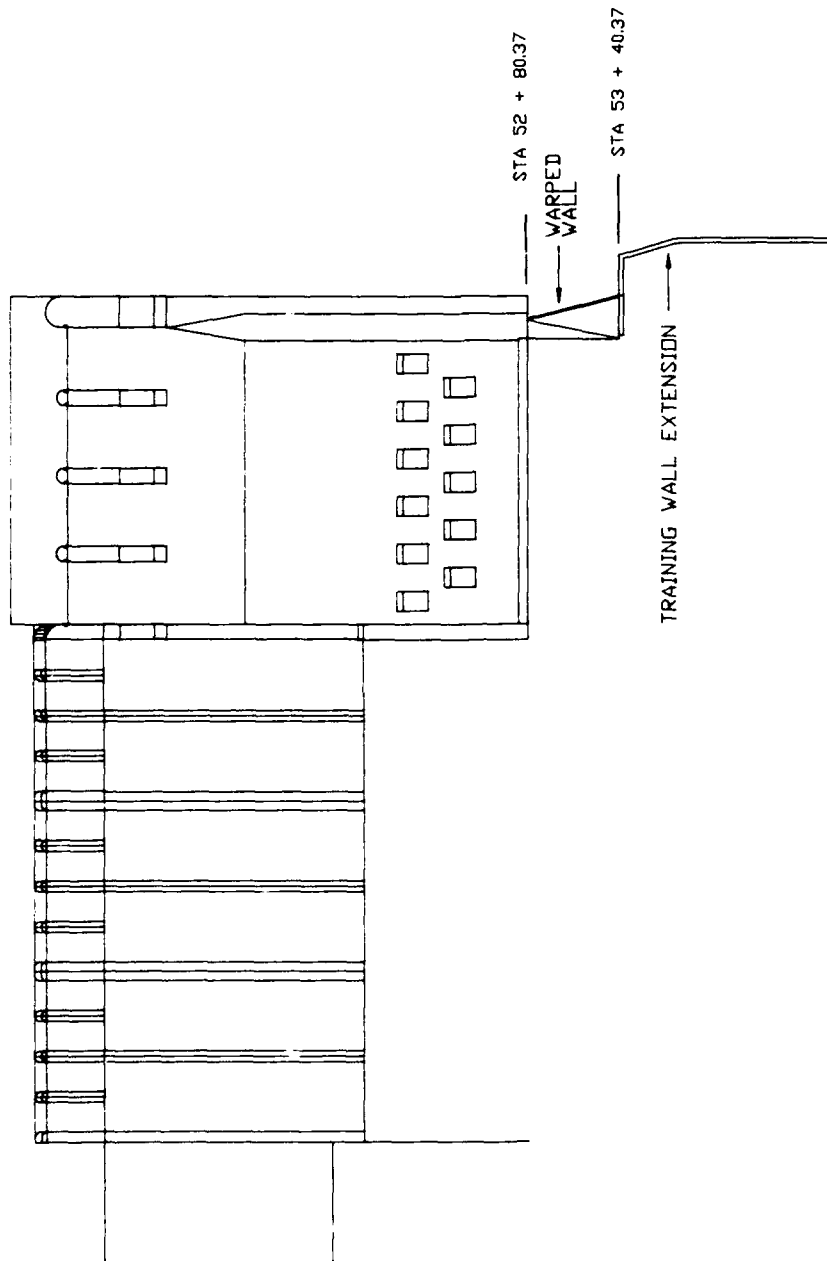
**VELOCITY AND FLOW PATTERNS**  
 STATION 8  
 SPILLWAY DISCHARGE 229,000 CFS  
 POWERHOUSE CLOSED  
 POOL EL 742.0  
 TAILWATER EL 675

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



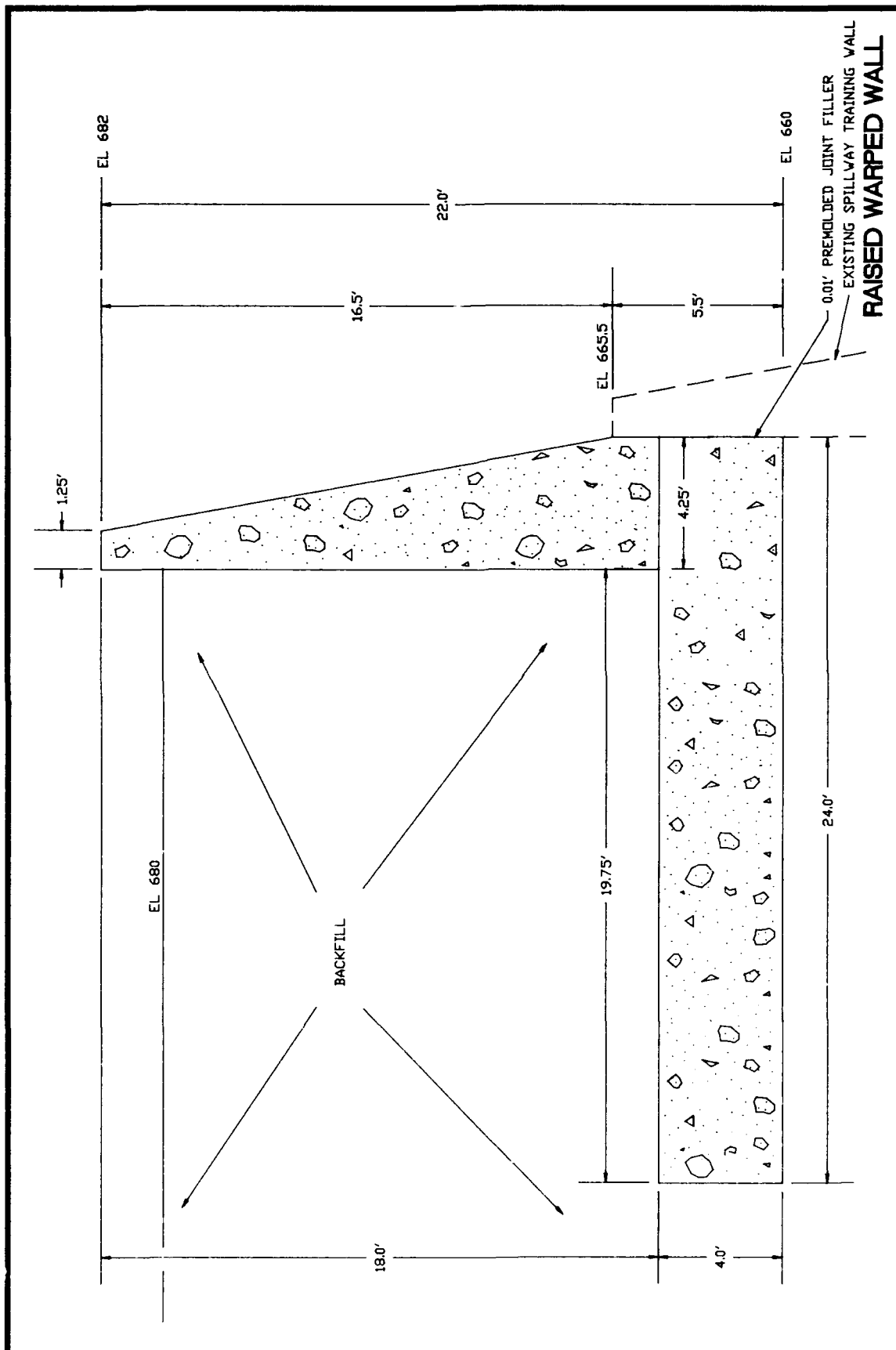
# **VELOCITY AND FLOW PATTERNS** STATION 9 SPILLWAY DISCHARGE 229,000 CFS POWERHOUSE CLOSED POOL EL 742.0 TAILWATER EL 675

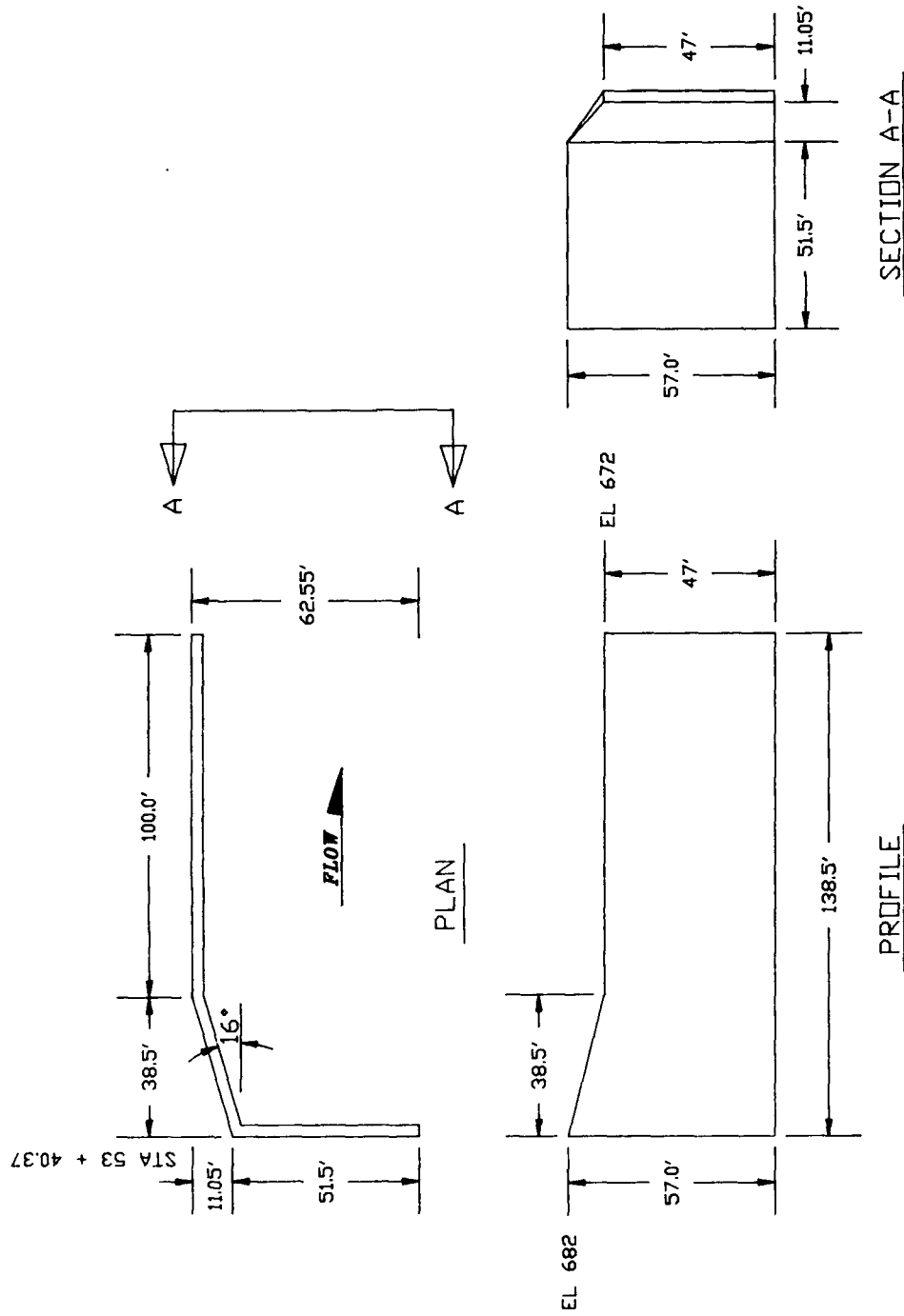
NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



MODIFIED TRAINING WALL







TRAINING WALL EXTENSION

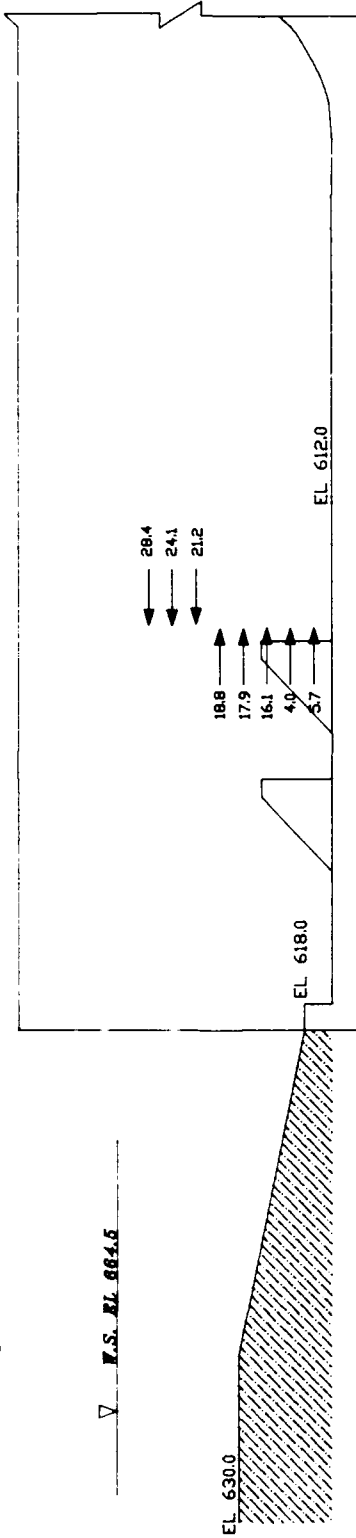
— Sta 60 + 96.76

— Sta 61 + 96.97

— Sta 62 + 80.97

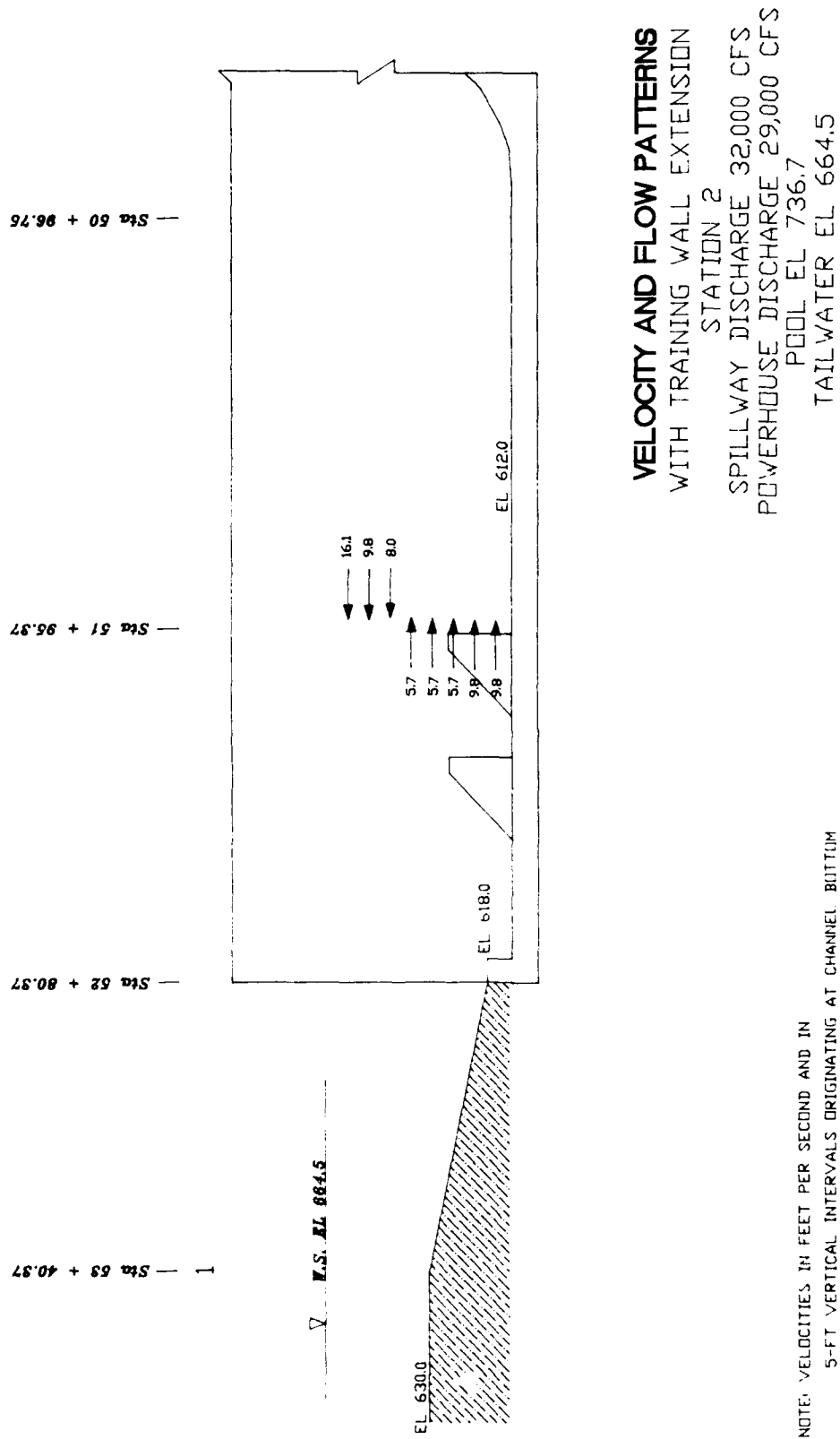
1 — Sta 63 + 40.97

▽ F.S. EL 664.5



**VELOCITY AND FLOW PATTERNS**  
WITH TRAINING WALL EXTENSION  
STATION 1  
SPILLWAY DISCHARGE 32,000 CFS  
POWERHOUSE DISCHARGE 29,000 CFS  
POOL EL 736.7  
TAILWATER EL 664.5

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



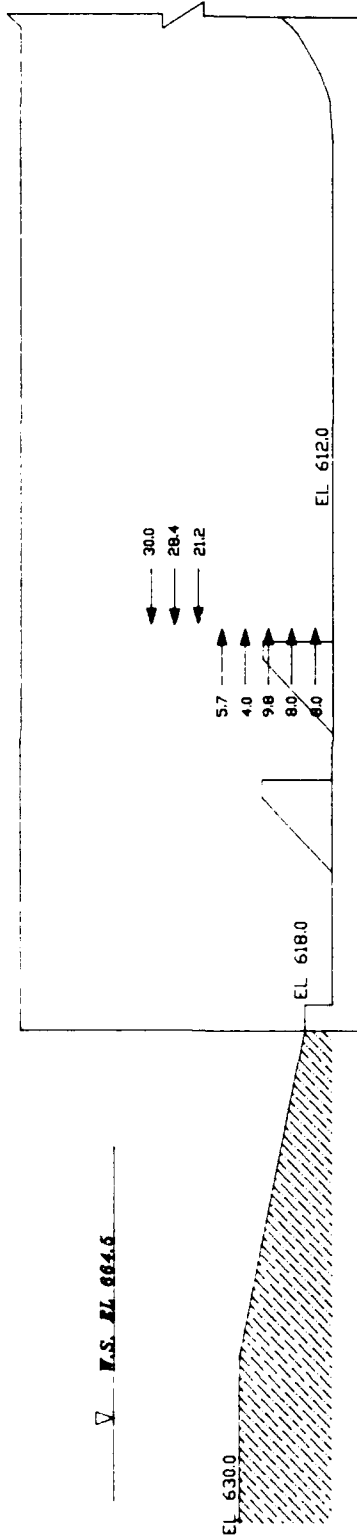
— Sta 50 + 96.76

— Sta 61 + 96.37

— Sta 52 + 80.37

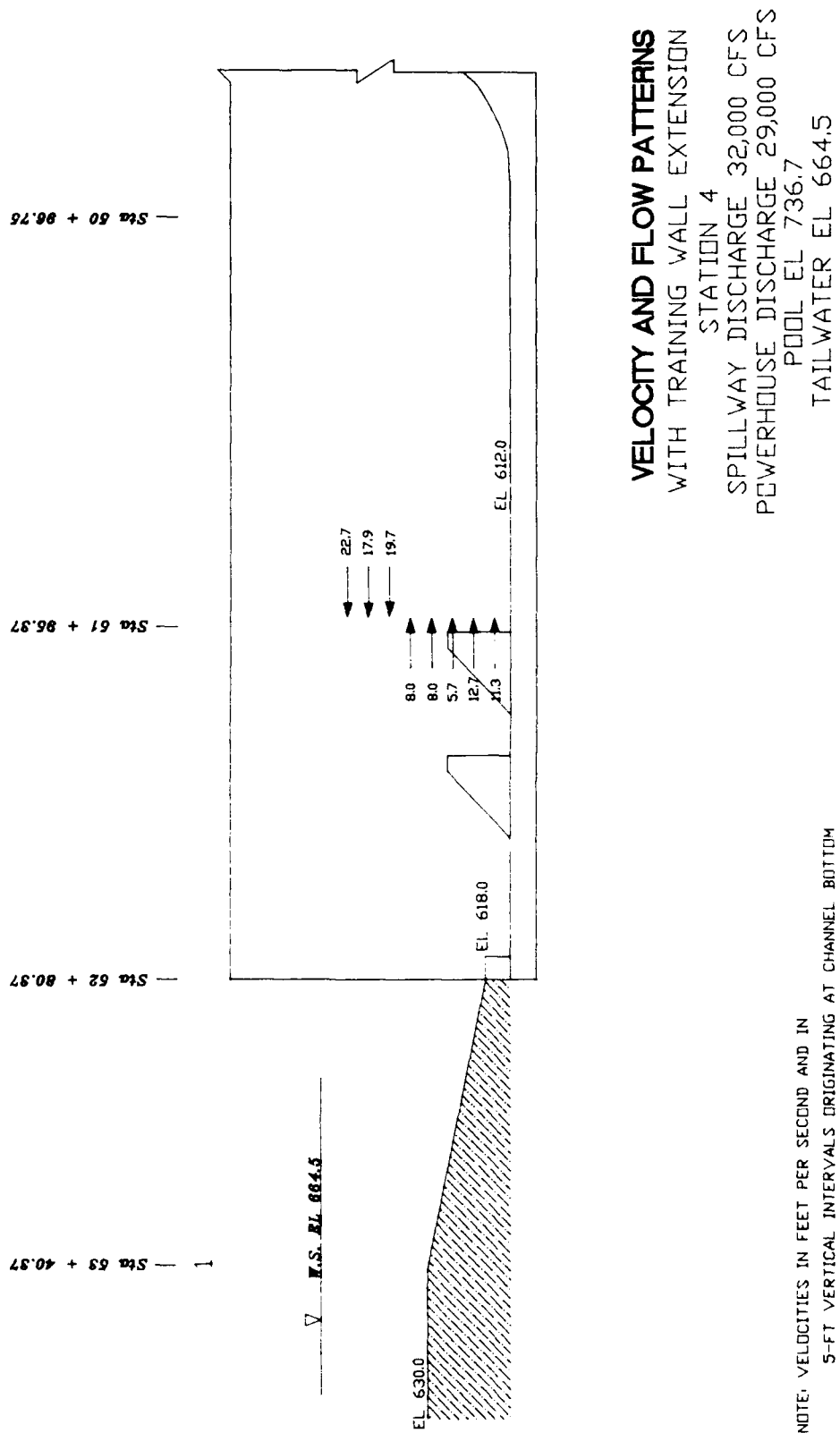
1 — Sta 63 + 40.37

▽ H.S. EL 664.5



**VELOCITY AND FLOW PATTERNS**  
WITH TRAINING WALL EXTENSION  
STATION 3  
SPILLWAY DISCHARGE 32,000 CFS  
POWERHOUSE DISCHARGE 29,000 CFS  
POOL EL 736.7  
TAILWATER EL 664.5

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



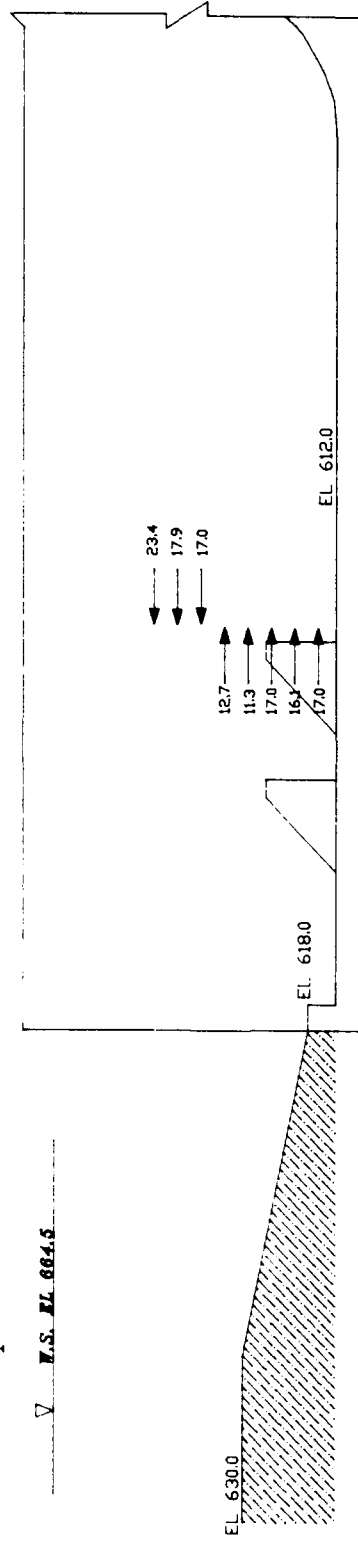
— Sta 60 + 96.76

— Sta 61 + 96.97

— Sta 62 + 80.97

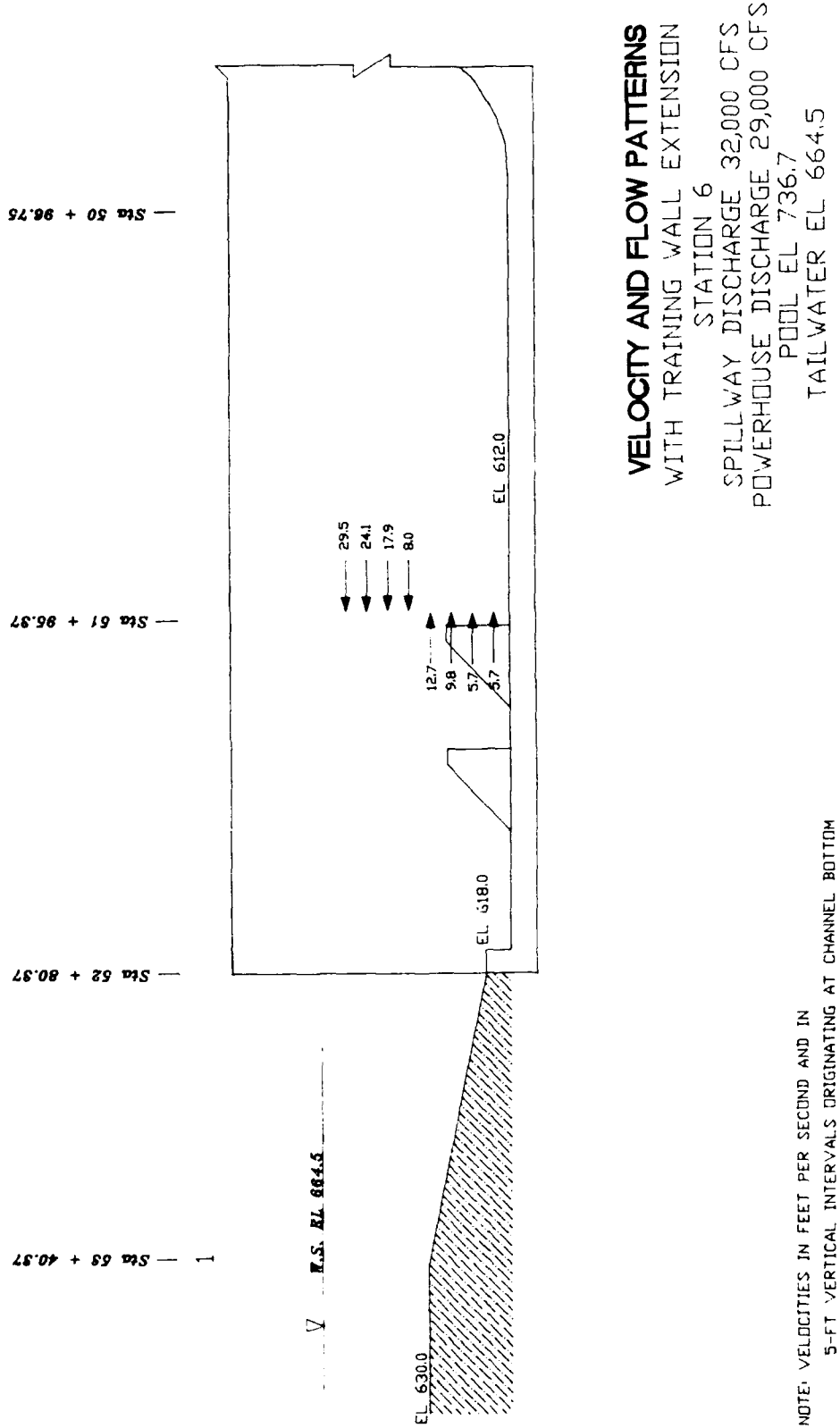
1 — Sta 63 + 40.97

▽ W.S. EL 664.5



**VELOCITY AND FLOW PATTERNS**  
WITH TRAINING WALL EXTENSION  
STATION 5  
SPILLWAY DISCHARGE 32,000 CFS  
POWERHOUSE DISCHARGE 29,000 CFS  
POOL EL 736.7  
TAILWATER EL 664.5

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM





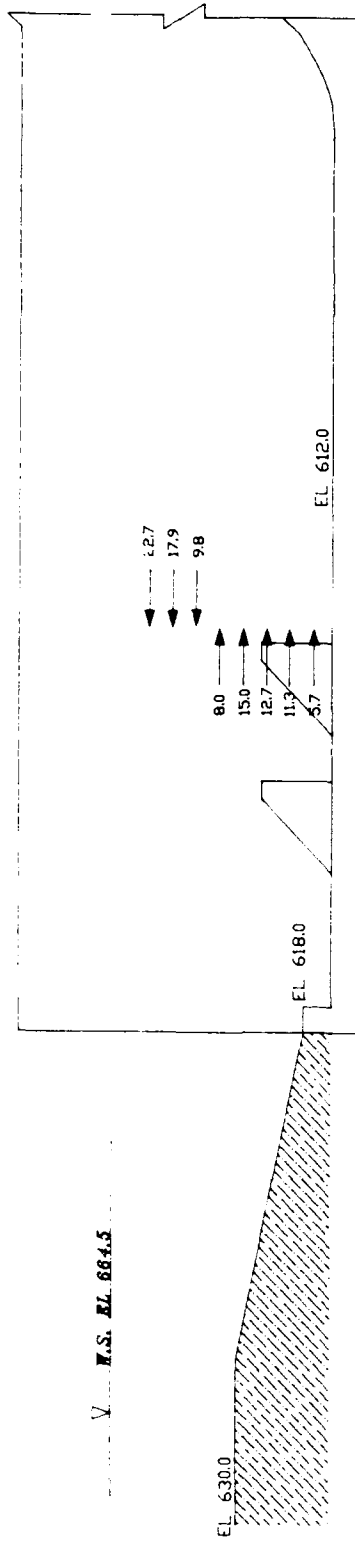
1 — Sta 53 + 40.37

— Sta 52 + 80.37

— Sta 51 + 96.97

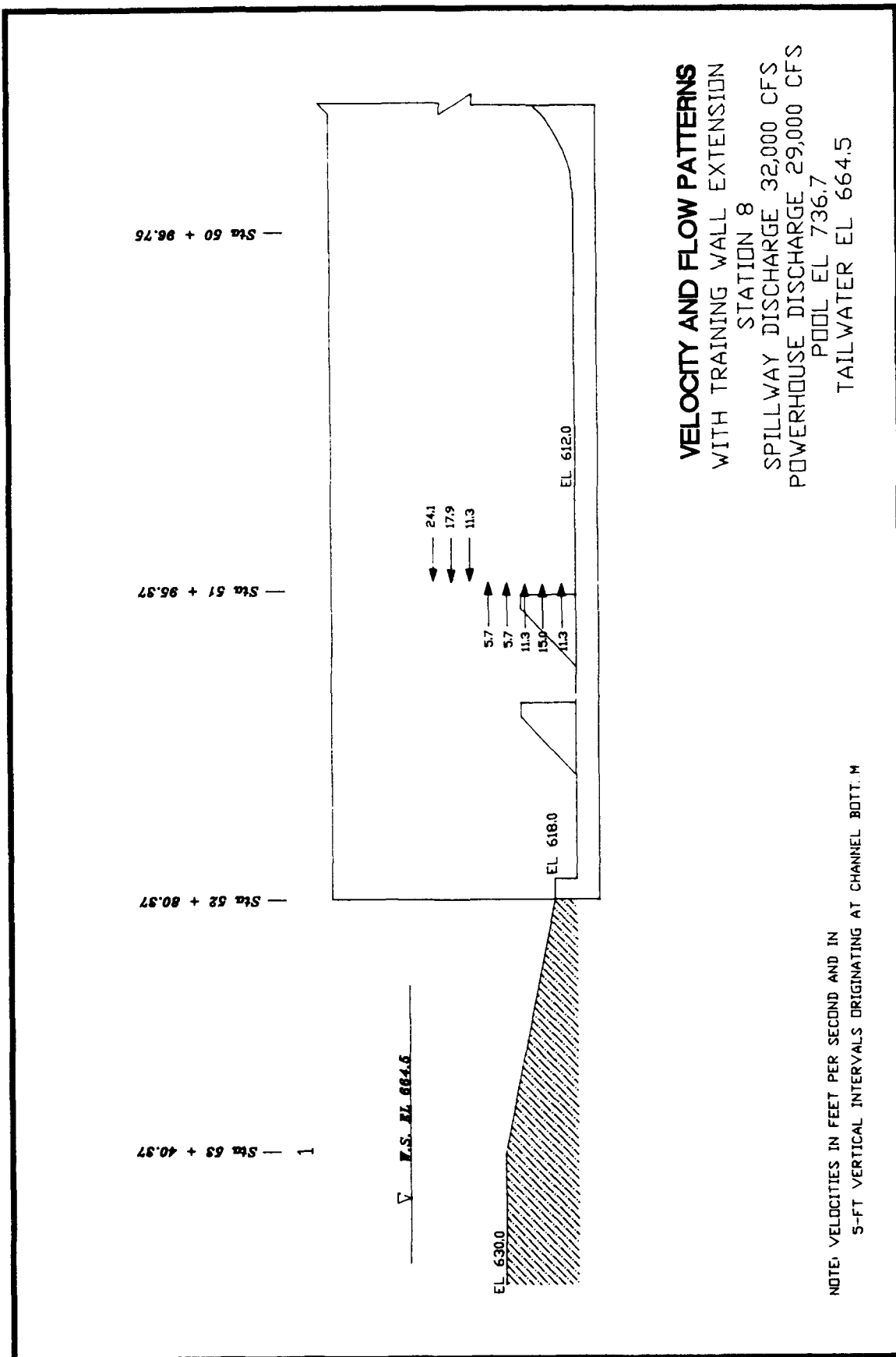
— Sta 50 + 96.75

V M.S. EL. 664.5



**VELOCITY AND FLOW PATTERNS**  
 WITH TRAINING WALL EXTENSION  
 STATION 7  
 SPILLWAY DISCHARGE 32,000 CFS  
 POWERHOUSE DISCHARGE 29,000 CFS  
 POOL EL 736.7  
 TAILWATER EL 664.5

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



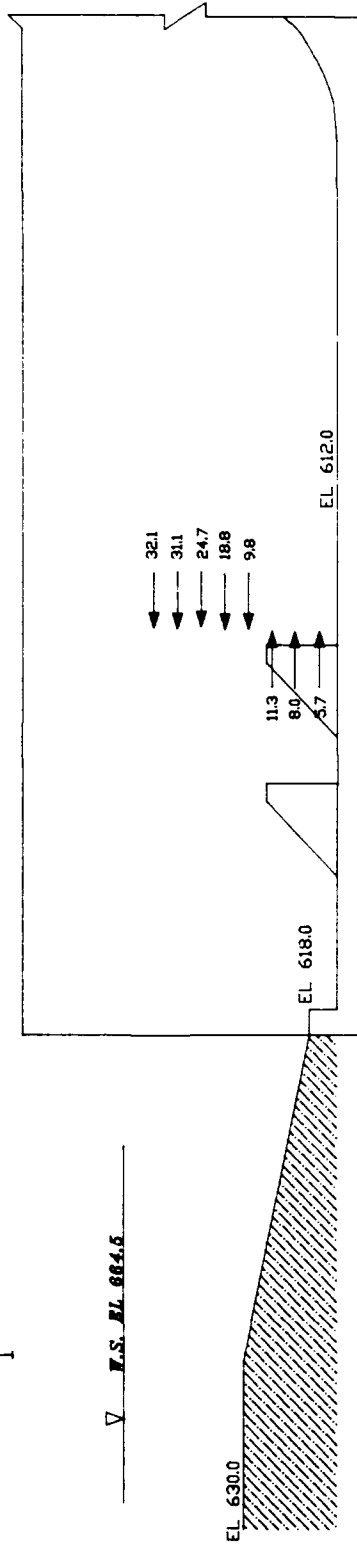
— Sta 60 + 96.75

— Sta 61 + 96.97

— Sta 62 + 80.97

1 — Sta 63 + 40.97

▽ W.S. EL 864.5



# VELOCITY AND FLOW PATTERNS WITH TRAINING WALL EXTENSION

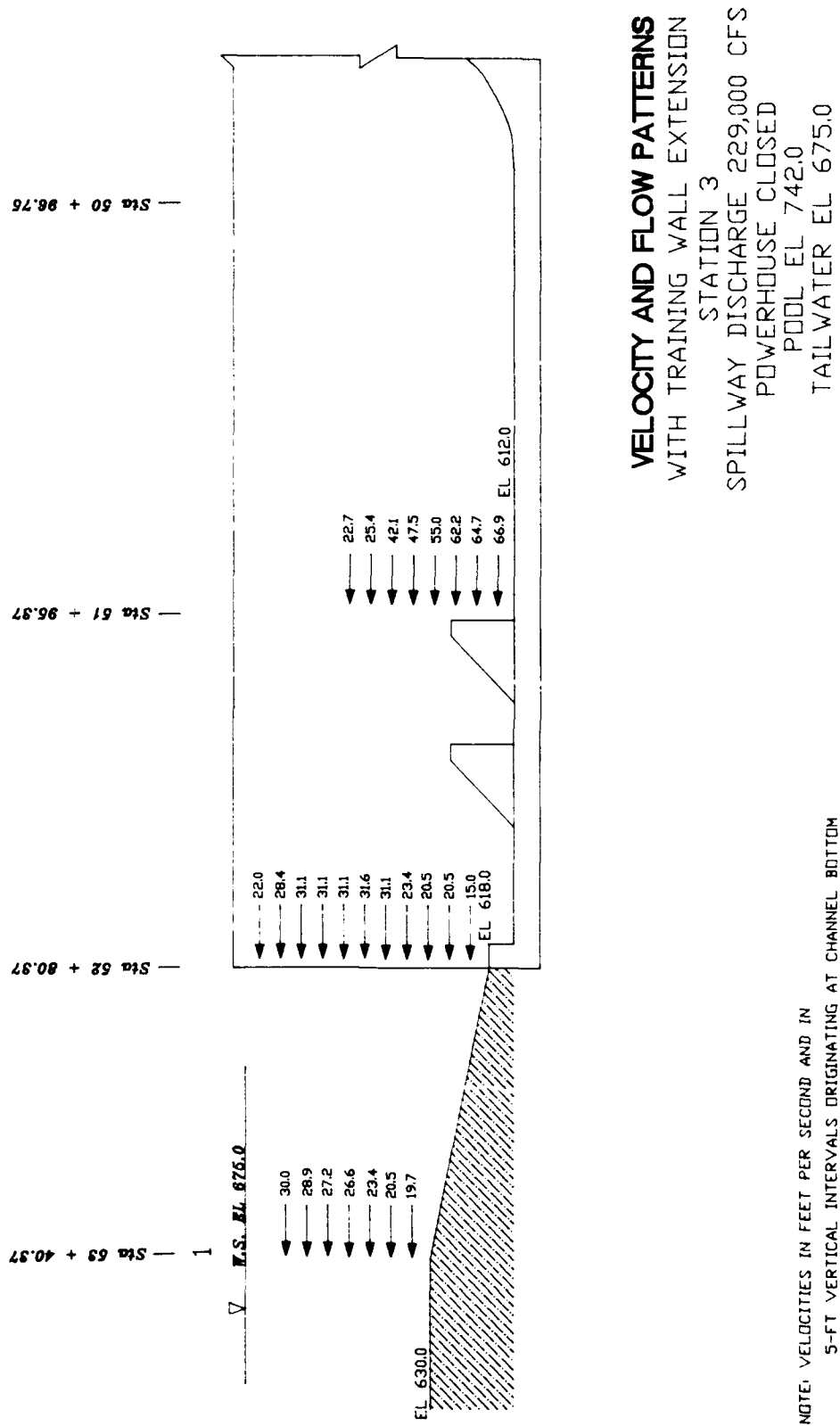
STATION 9

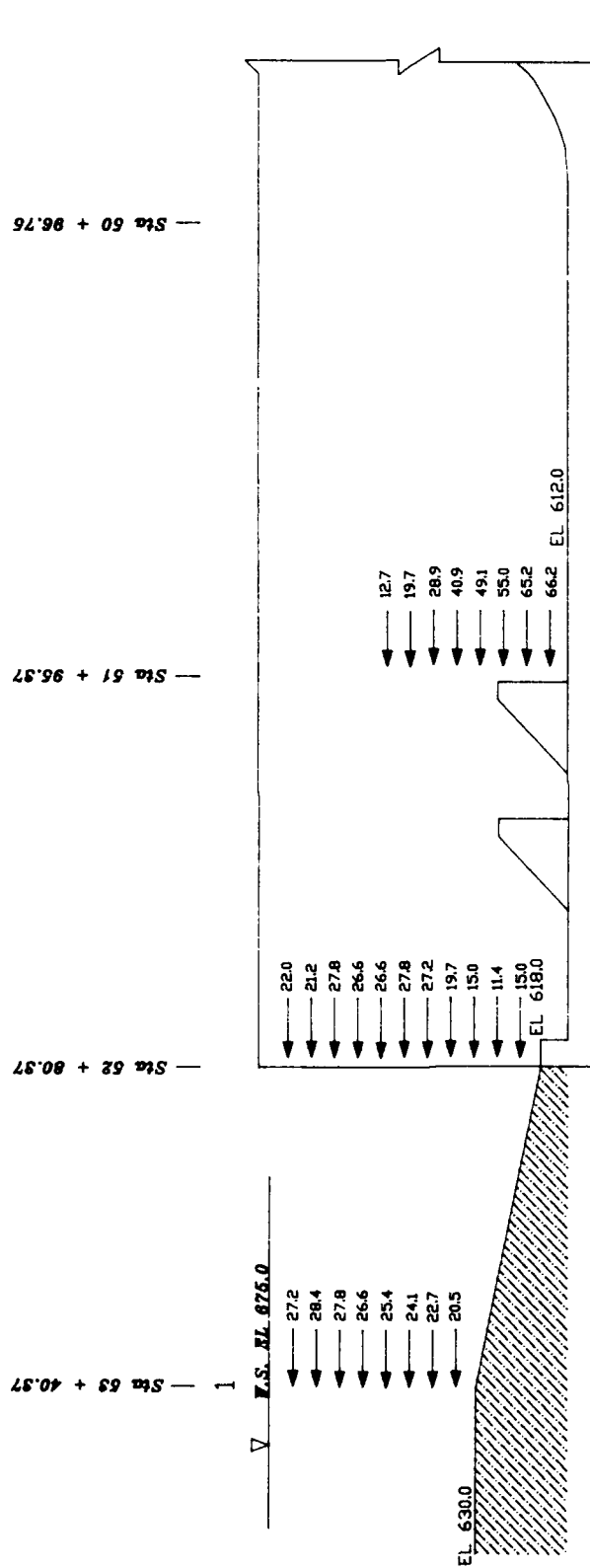
DISCHARGE 61,000 CFS

POOL EL 736.7

TAILWATER EL 664.5

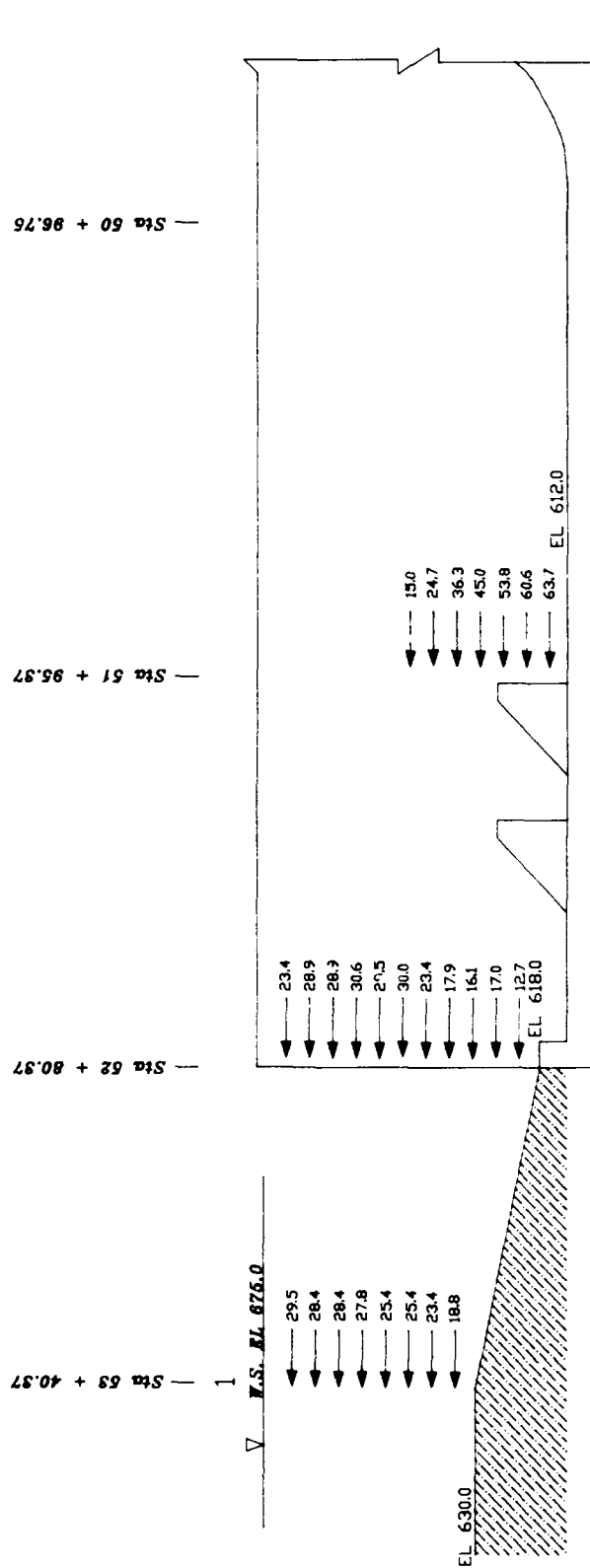
NOTE: VELOCITIES IN FEET PER SECOND AND IN  
5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM





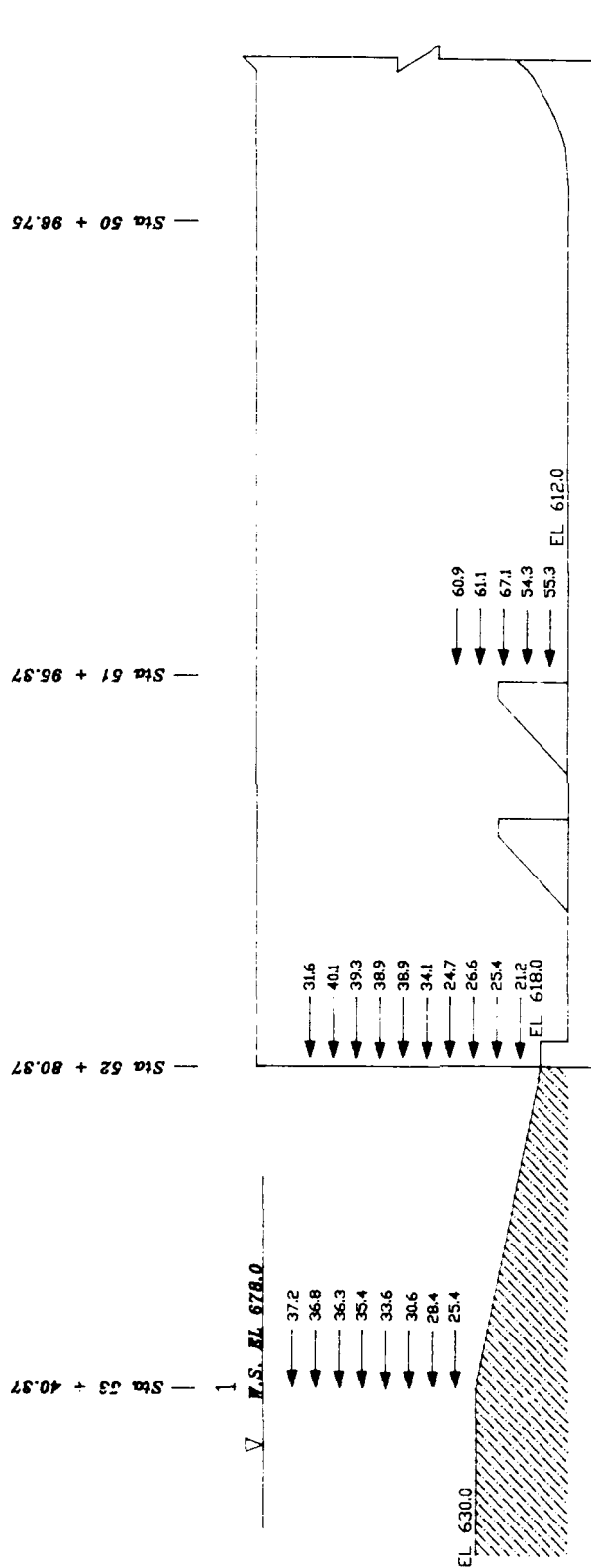
**VELOCITY AND FLOW PATTERNS**  
 WITH TRAINING WALL EXTENSION  
 STATION 5  
 SPILLWAY DISCHARGE 229,000 CFS  
 POWERHOUSE CLOSED  
 P.I.D.L. EL 742.0  
 TAILWATER EL 675.0

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



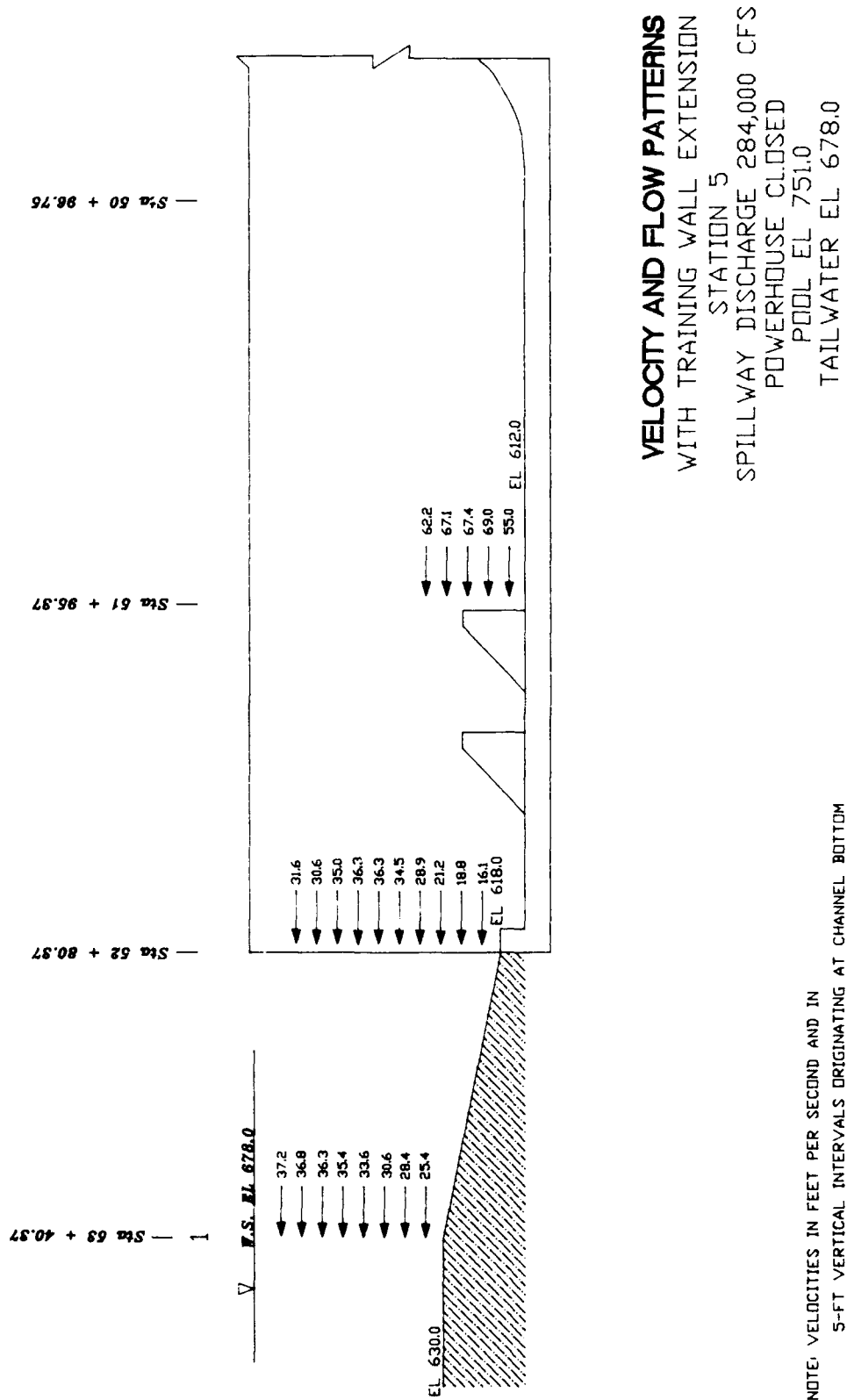
**VELOCITY AND FLOW PATTERNS**  
 WITH TRAINING WALL EXTENSION  
 STATION 7  
 SPILLWAY DISCHARGE 229,000 CFS  
 POWERHOUSE CLOSED  
 POOL EL 742.0  
 TAILWATER EL 675.0

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM



**VELOCITY AND FLOW PATTERNS**  
 WITH TRAINING WALL EXTENSION  
 STATION 3  
 SPILLWAY DISCHARGE 284,000 CFS  
 POWERHOUSE CLOSED  
 POOL EL 751.0  
 TAILWATER EL 678.0

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM





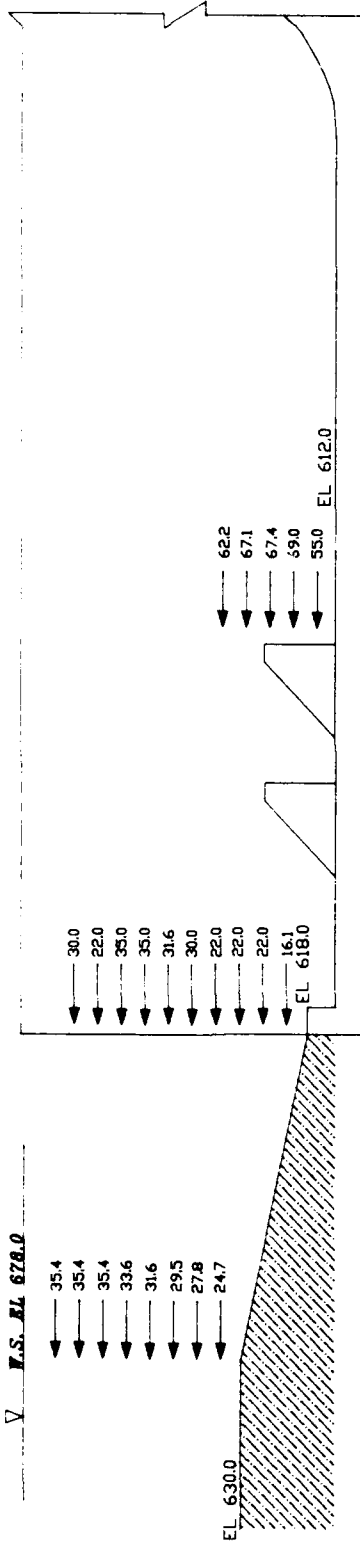
1 — Sta 63 + 40.97  
 V F.S. EL 678.0

EL 630.0  
 35.4  
 35.4  
 35.4  
 33.6  
 31.6  
 29.5  
 27.8  
 24.7

— Sta 62 + 80.97

— Sta 51 + 95.97

— Sta 50 + 96.76



**VELOCITY AND FLOW PATTERNS**  
 WITH TRAINING WALL EXTENSION  
 STATION 7  
 SPILLWAY DISCHARGE 284,000 CFS  
 POWERHOUSE CLOSED  
 POOL EL 751.0  
 TAILWATER EL 678.0

NOTE: VELOCITIES IN FEET PER SECOND AND IN  
 5-FT VERTICAL INTERVALS ORIGINATING AT CHANNEL BOTTOM

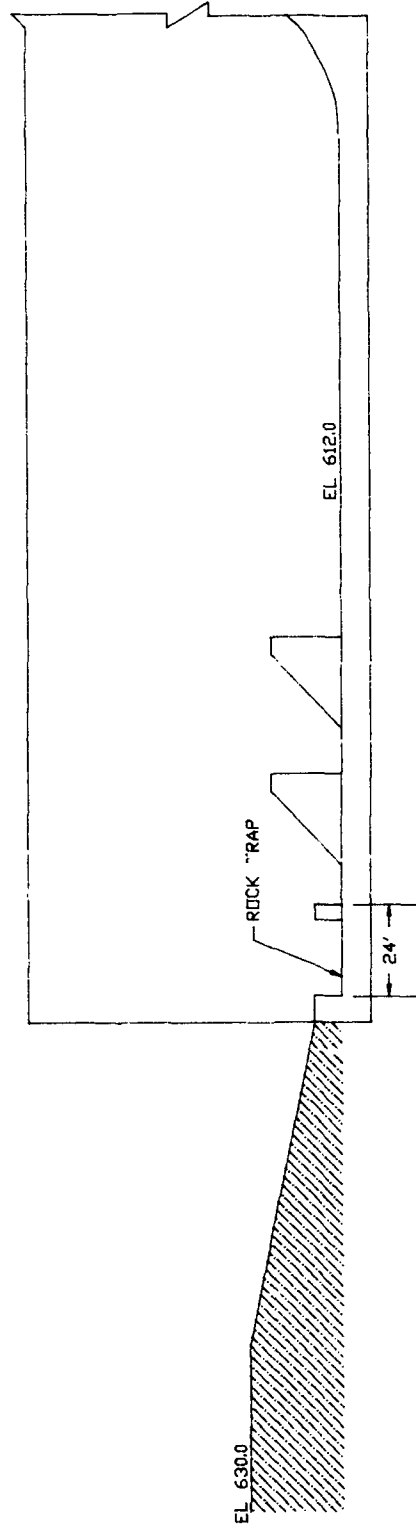
STILLING BASIN ROCK TRAP

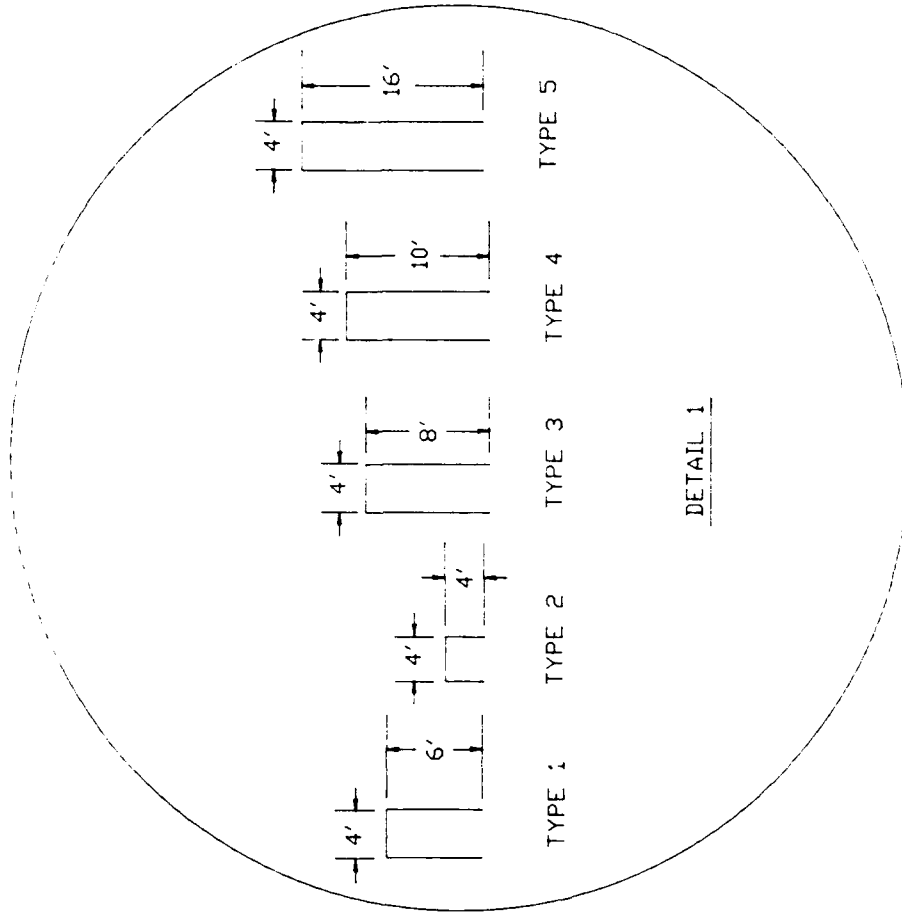
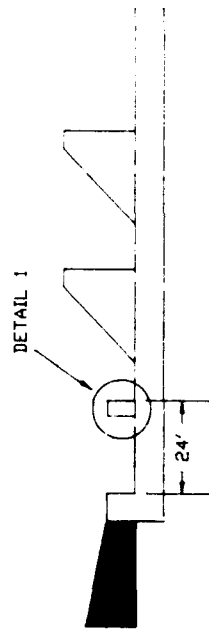
— Sta 50 + 96.76

— Sta 61 + 96.97

— Sta 62 + 90.97

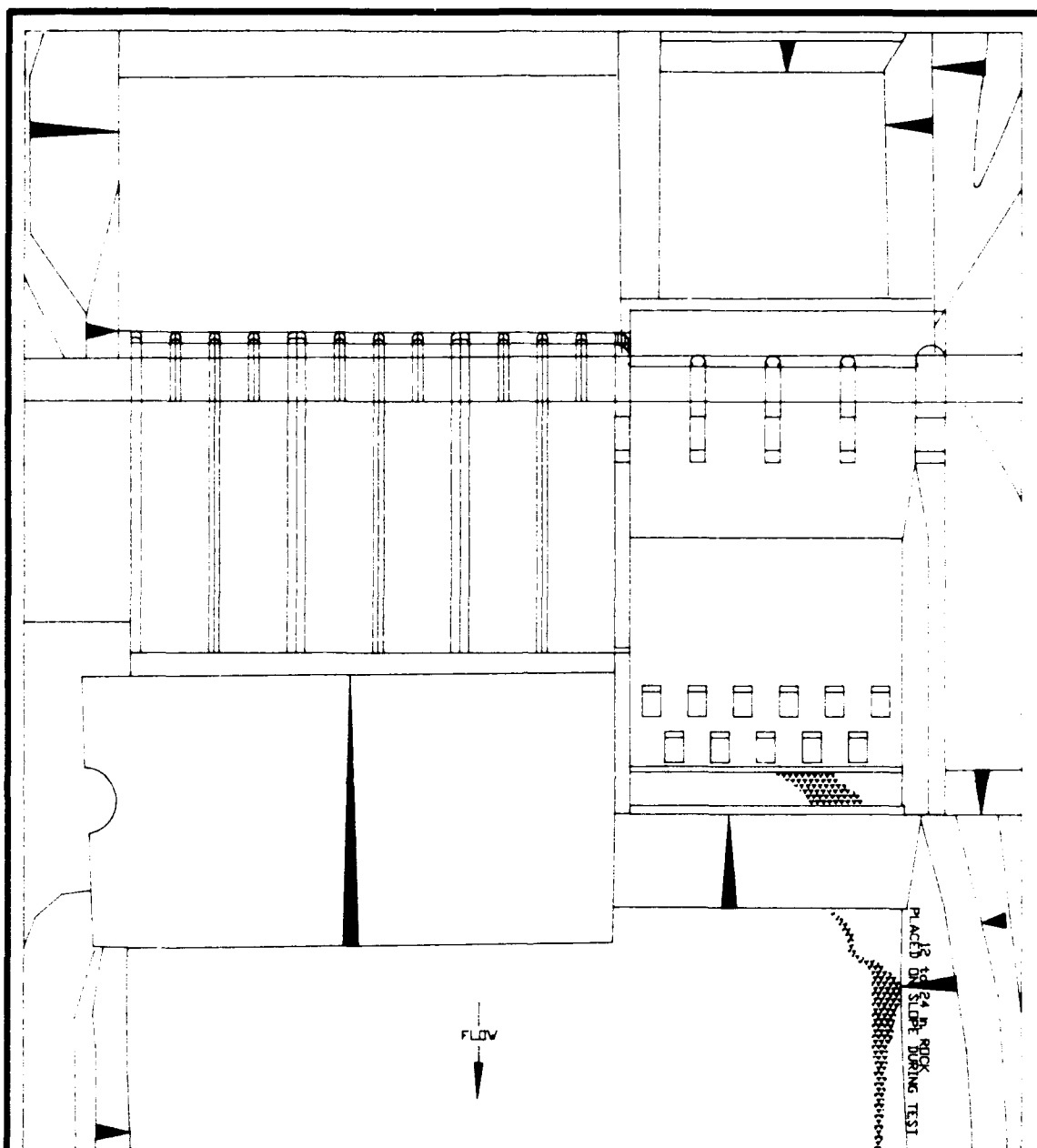
— Sta 63 + 40.97





DETAIL 1

# DETAIL OF ROCK TRAP



### STONE DISPLACEMENT TEST NO. 1

DISCHARGE :

SPILLWAY 32,000 CFS

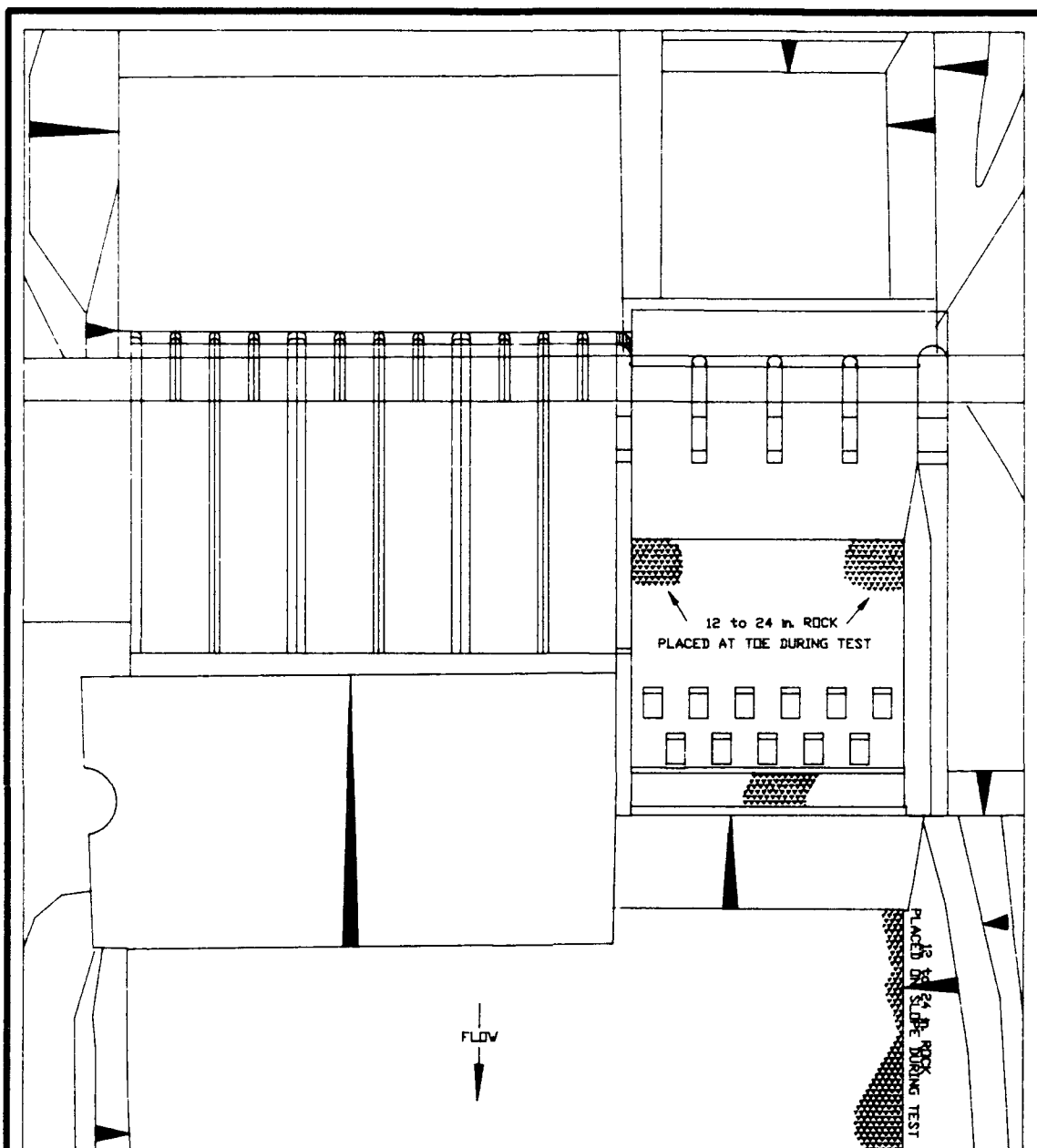
POWERHOUSE 29,000 CFS

TAINTER GATES OPEN 6.2 FT

5 GATES OPEN IN POWERHOUSE

POOL EL 736.7, TAILWATER EL 664.5

TYPE 1 ROCK TRAP



## STONE DISPLACEMENT TEST NO. 2

DISCHARGE :

SPILLWAY 32,000 CFS

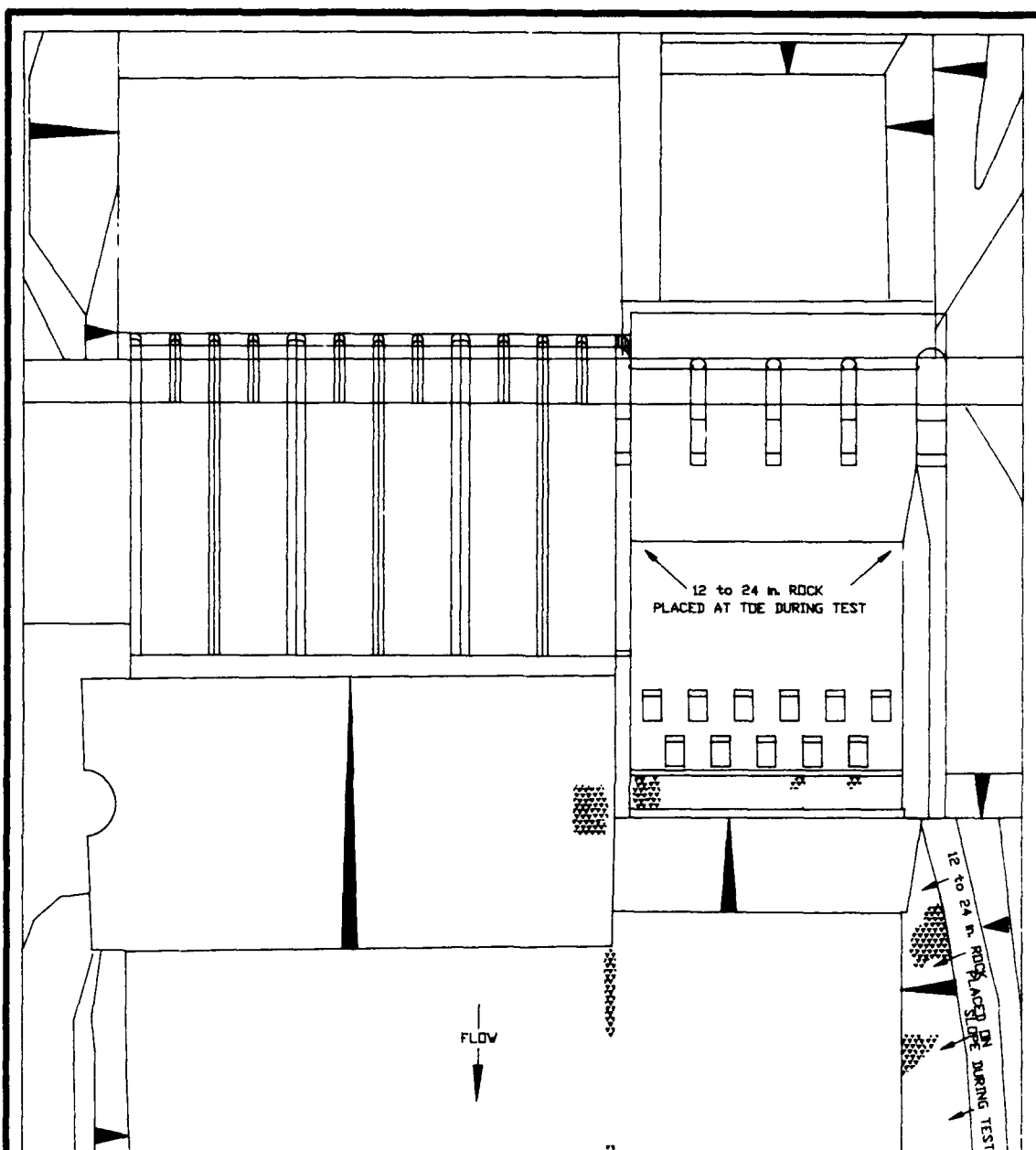
POWERHOUSE 29,000 CFS

TAINTER GATES OPEN 6.2 FT

5 GATES OPEN IN POWERHOUSE

POOL EL 736.7, TAILWATER EL 664.5

TYPE 1 ROCK TRAP



### STONE DISPLACEMENT TEST NO. 3

DISCHARGE :

SPILLWAY 200,000 CFS

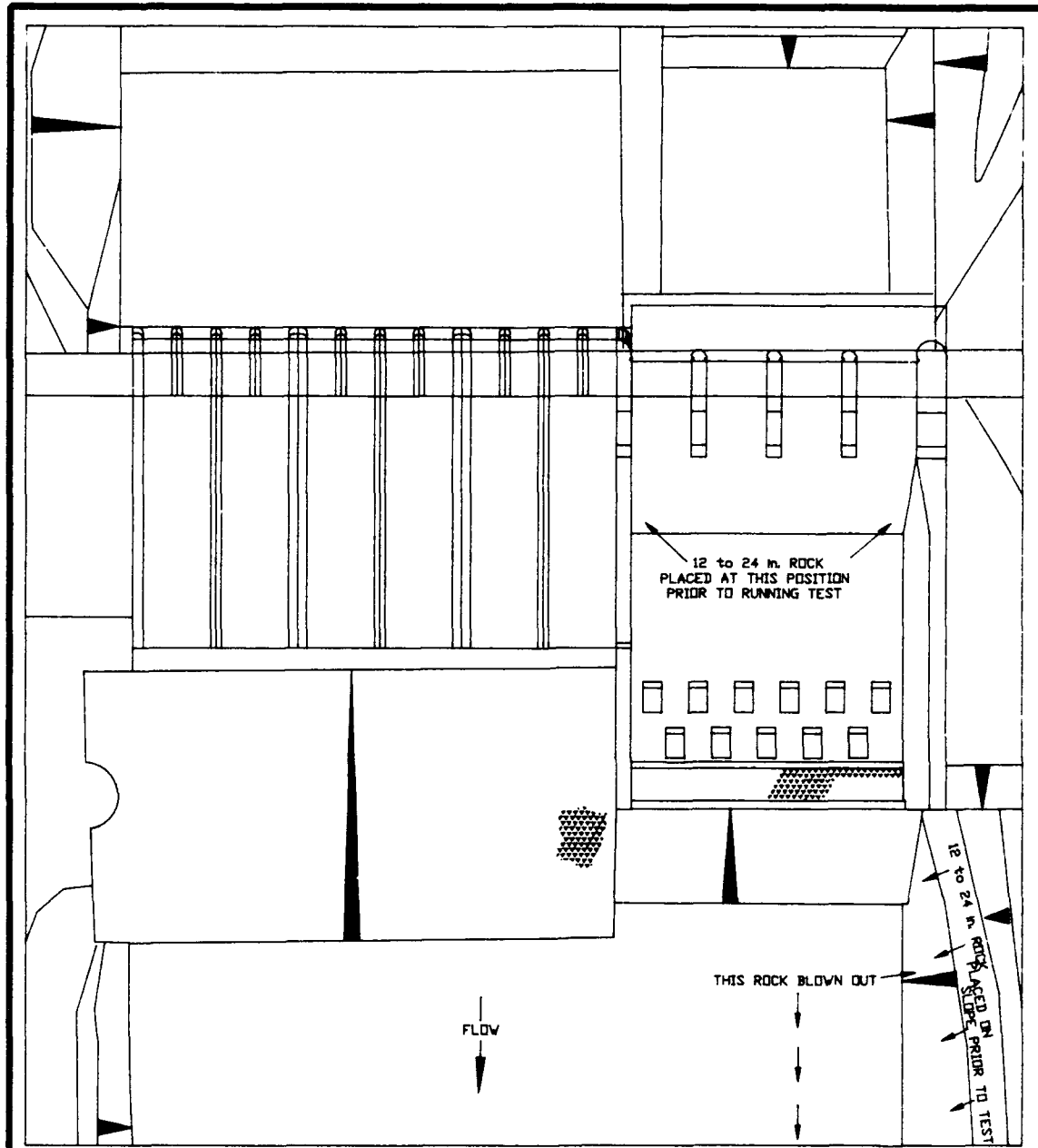
POWERHOUSE 29,000 CFS

TANTIER GATES FULL OPEN

5 GATES OPEN IN POWERHOUSE

POOL EL 742.0, TAILWATER EL 675.0

TYPE 1 ROCK TRAP



#### STONE DISPLACEMENT TEST NO. 4

DISCHARGE :

SPELLWAY 200,000 CFS

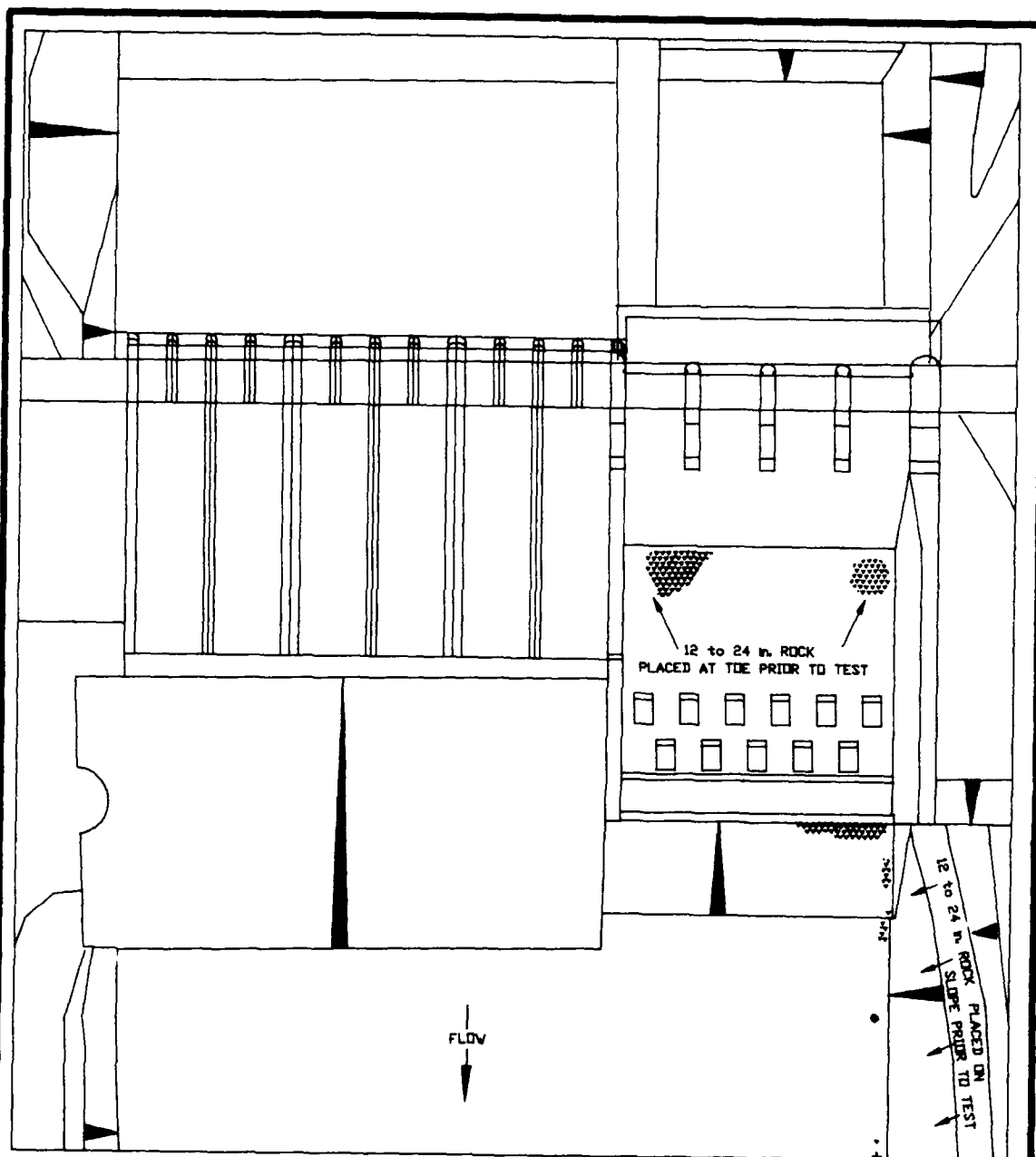
POWERHOUSE 29,000 CFS

TAINTER GATES FULL OPEN

5 GATES OPEN IN POWERHOUSE

POOL EL 742.0, TAILWATER EL 665.0

TYPE 1 ROCK TRAP



### STONE DISPLACEMENT TEST NO. 7

DISCHARGE :

SPILLWAY 32,000 CFS

POWERHOUSE 29,000 CFS

TAINTER GATES OPEN 6.2 FT

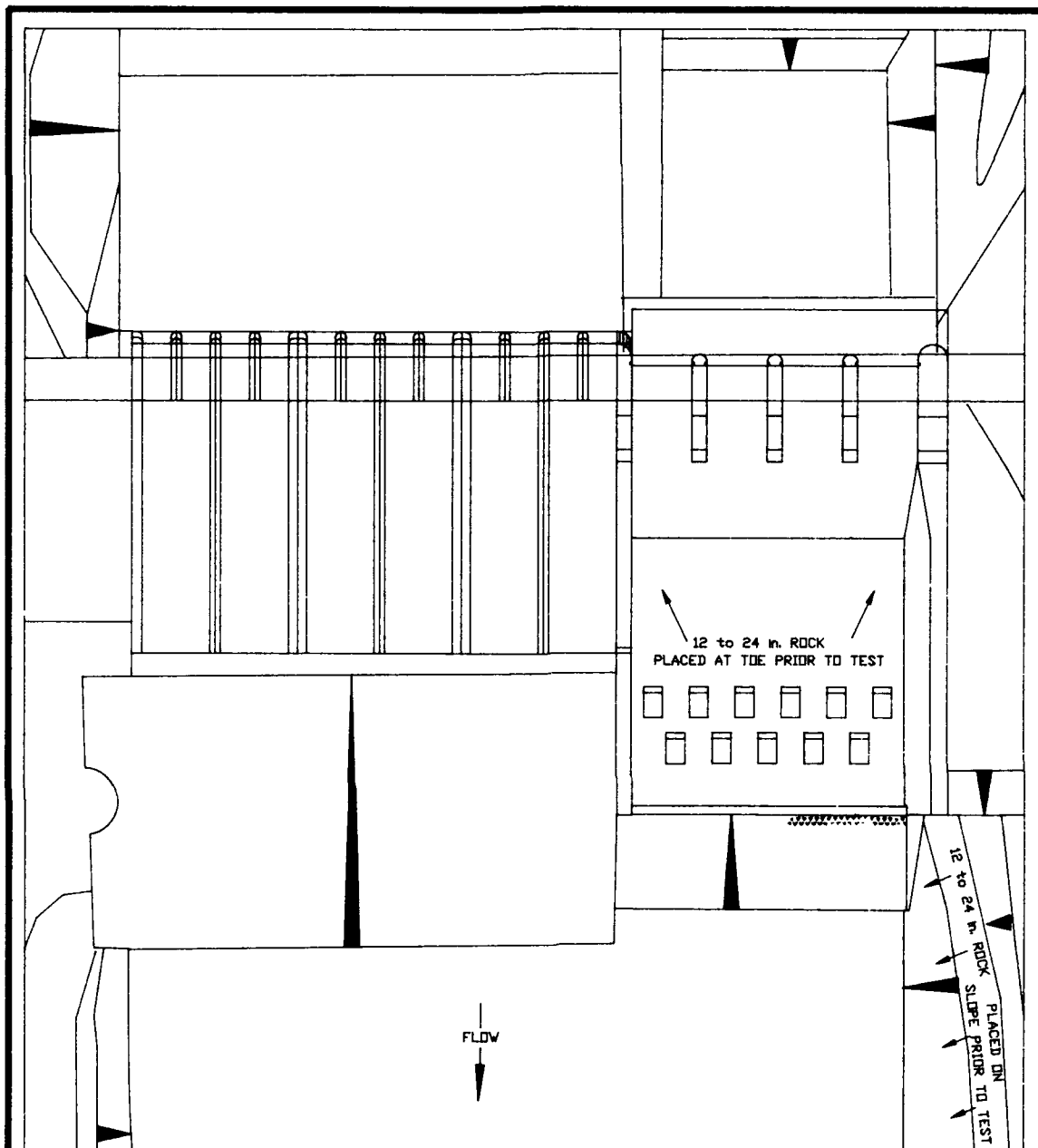
5 GATES OPEN IN POWERHOUSE

POOL EL 736.7, TAILWATER EL 664.5

TYPE 1 ROCK TRAP

6 FT ADDED TO END SILL HEIGHT





### STONE DISPLACEMENT TEST NO. 8

DISCHARGE :

SPILLWAY 200,000 CFS

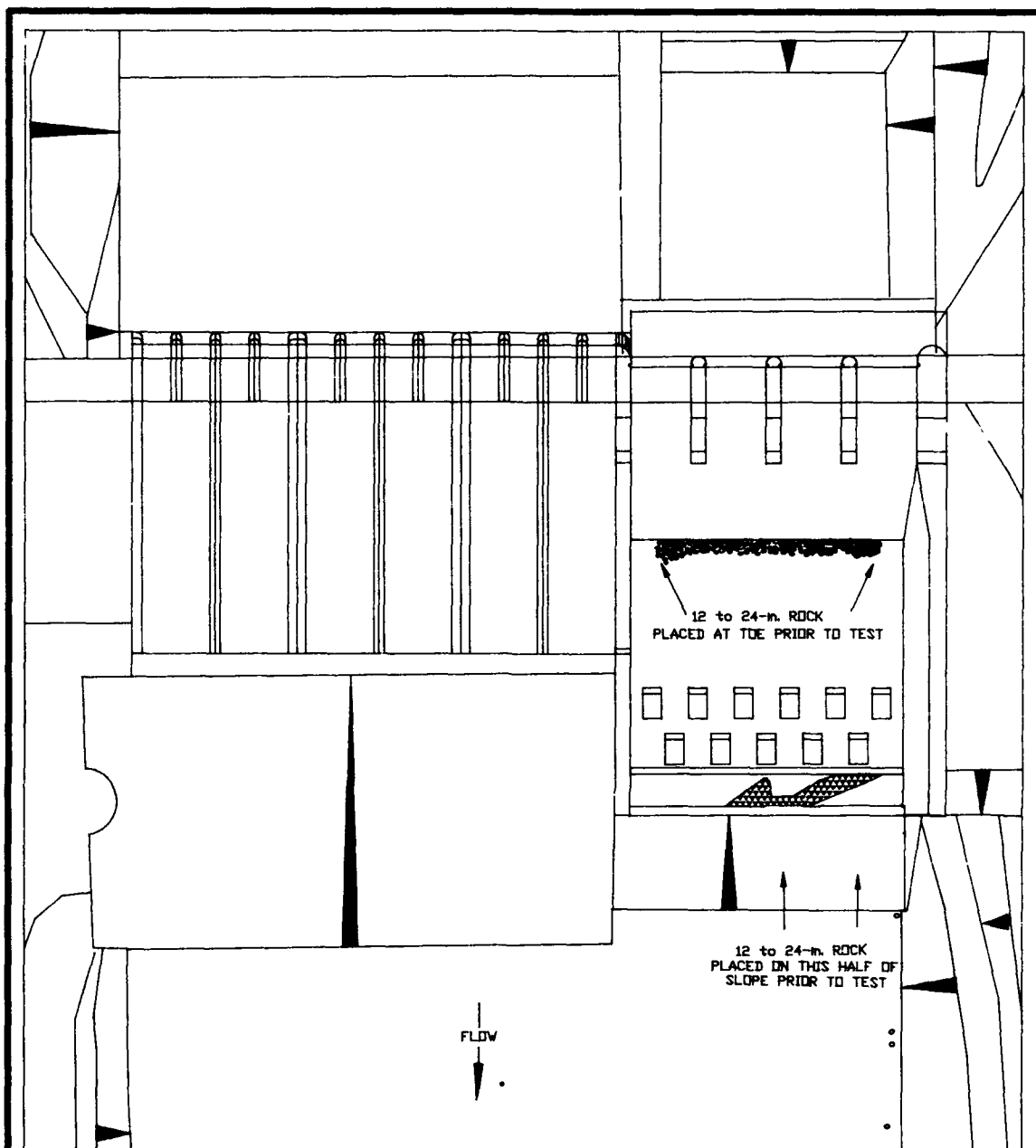
POWERHOUSE 29,000 CFS

TAINTER GATES FULL OPEN

5 GATES OPEN IN POWERHOUSE

POOL EL 742.0, TAILWATER EL 675.0

6 FT ADDED TO END SILL HEIGHT



# **STONE DISPLACEMENT TEST NO. 14**

DISCHARGE :

SPILLWAY 32,000 CFS

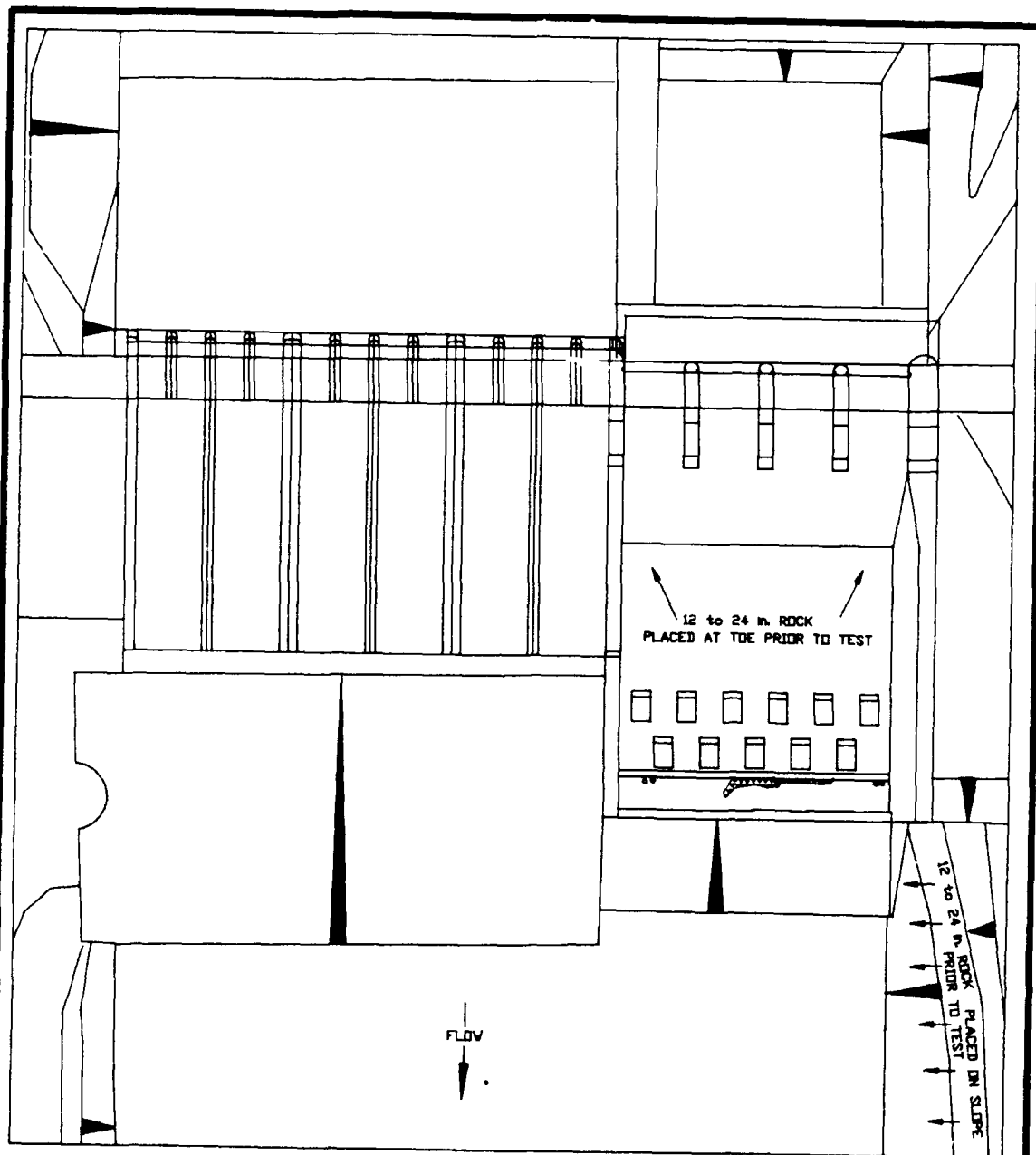
POWERHOUSE 29,000 CFS

TAINTER GATES OPEN 6.2 FT

5 GATES OPEN IN POWERHOUSE

POOL EL 736.7, TAILWATER EL 664.5

TYPE 2 ROCK TRAP



### STONE DISPLACEMENT TEST NO. 15

DISCHARGE :

SPILLWAY 200,000 CFS

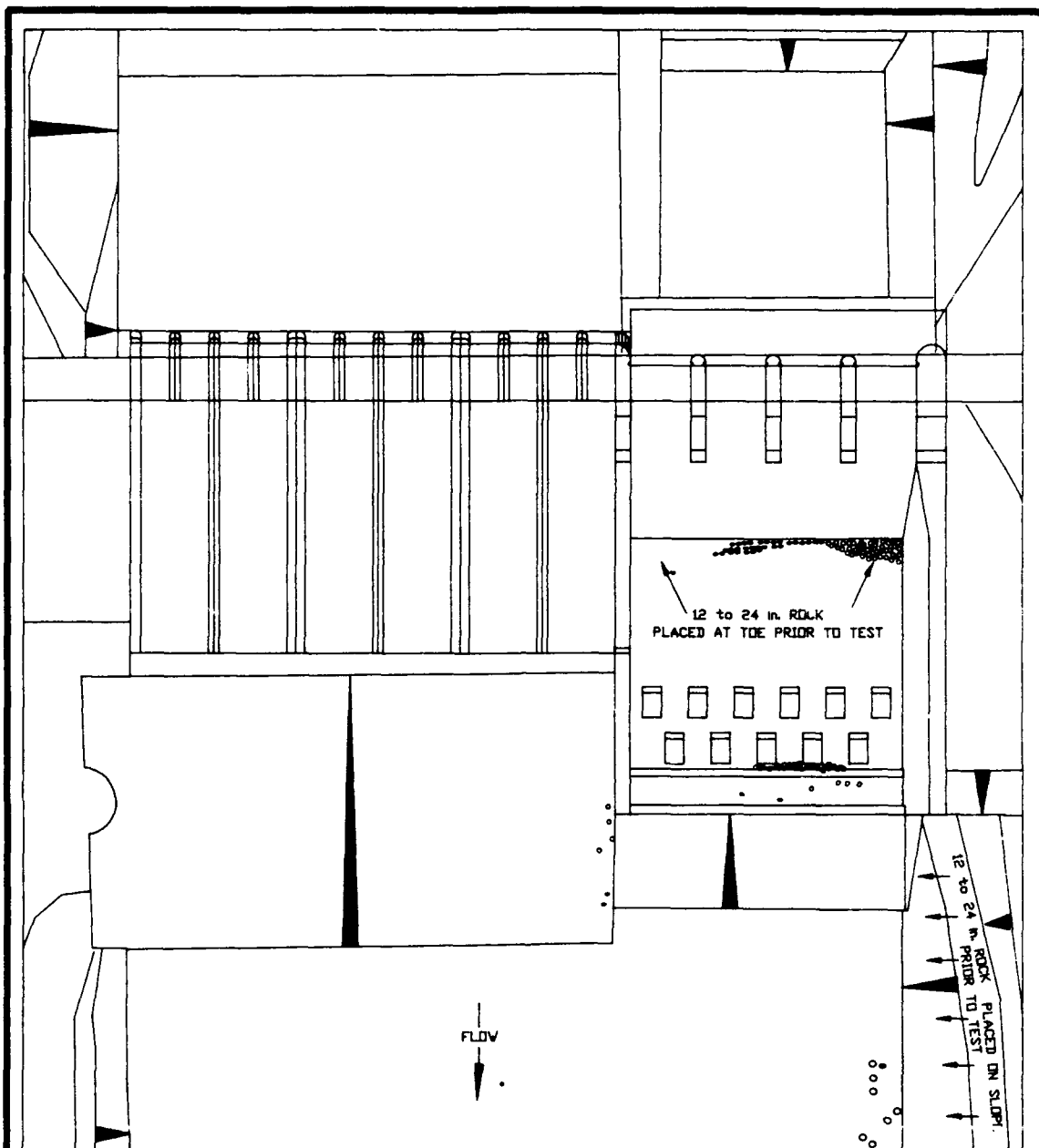
POWERHOUSE 29,000 CFS

TAINTER GATES FULL OPEN

5 GATES OPEN IN POWERHOUSE

POOL EL 742.0, TAILWATER EL 675.0

TYPE 2 ROCK TRAP



### STONE DISPLACEMENT TEST NO. 16

DISCHARGE :

SPILLWAY 61,000 CFS

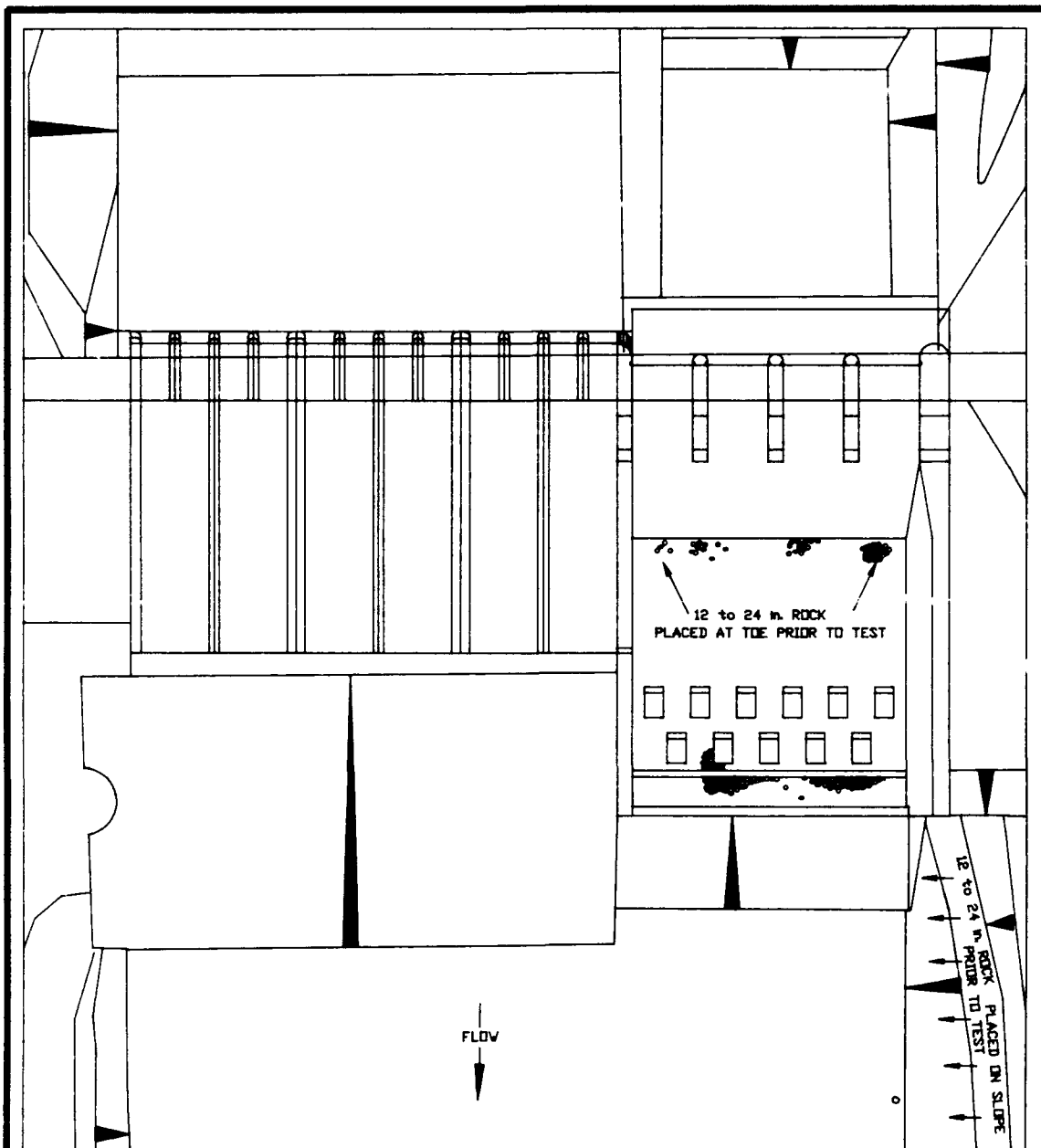
POWERHOUSE 29,000 CFS

TAINTER GATES OPEN 112 FT

5 GATES OPEN IN POWERHOUSE

POOL EL 740.0, TAILWATER EL 668.0

TYPE 2 ROCK TRAP



# **STONE DISPLACEMENT TEST NO. 17**

DISCHARGE :

SPILLWAY 66,000 CFS

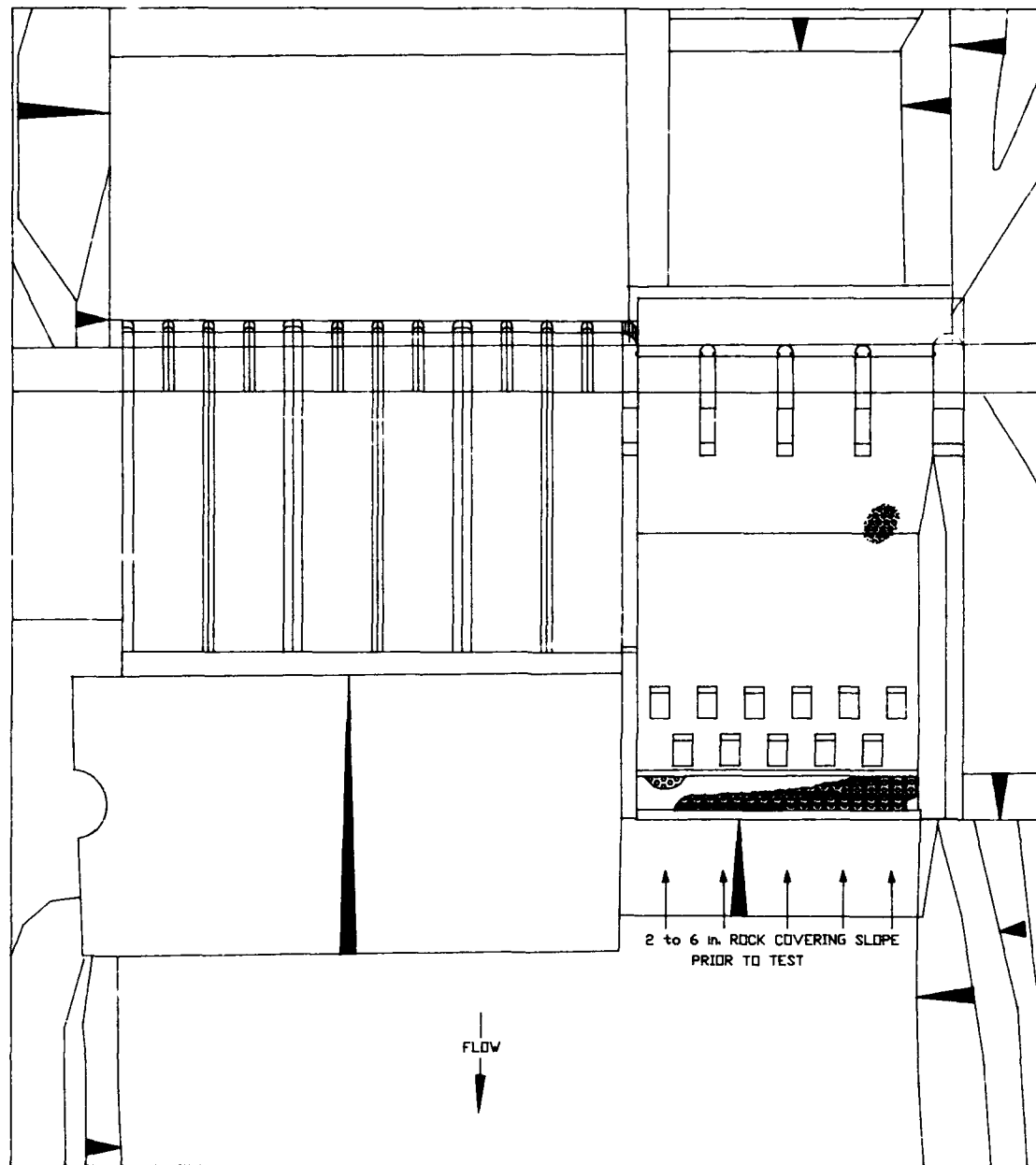
POWERHOUSE 29,000 CFS

TAINTER GATES OPEN 12.0 FT

5 GATES OPEN IN POWERHOUSE

POOL EL 740.0, TAILWATER EL 668.0

TYPE 2 ROCK TRAP



### STONE DISPLACEMENT TEST NO. 21

DISCHARGE :

SPILLWAY 32,000 CFS

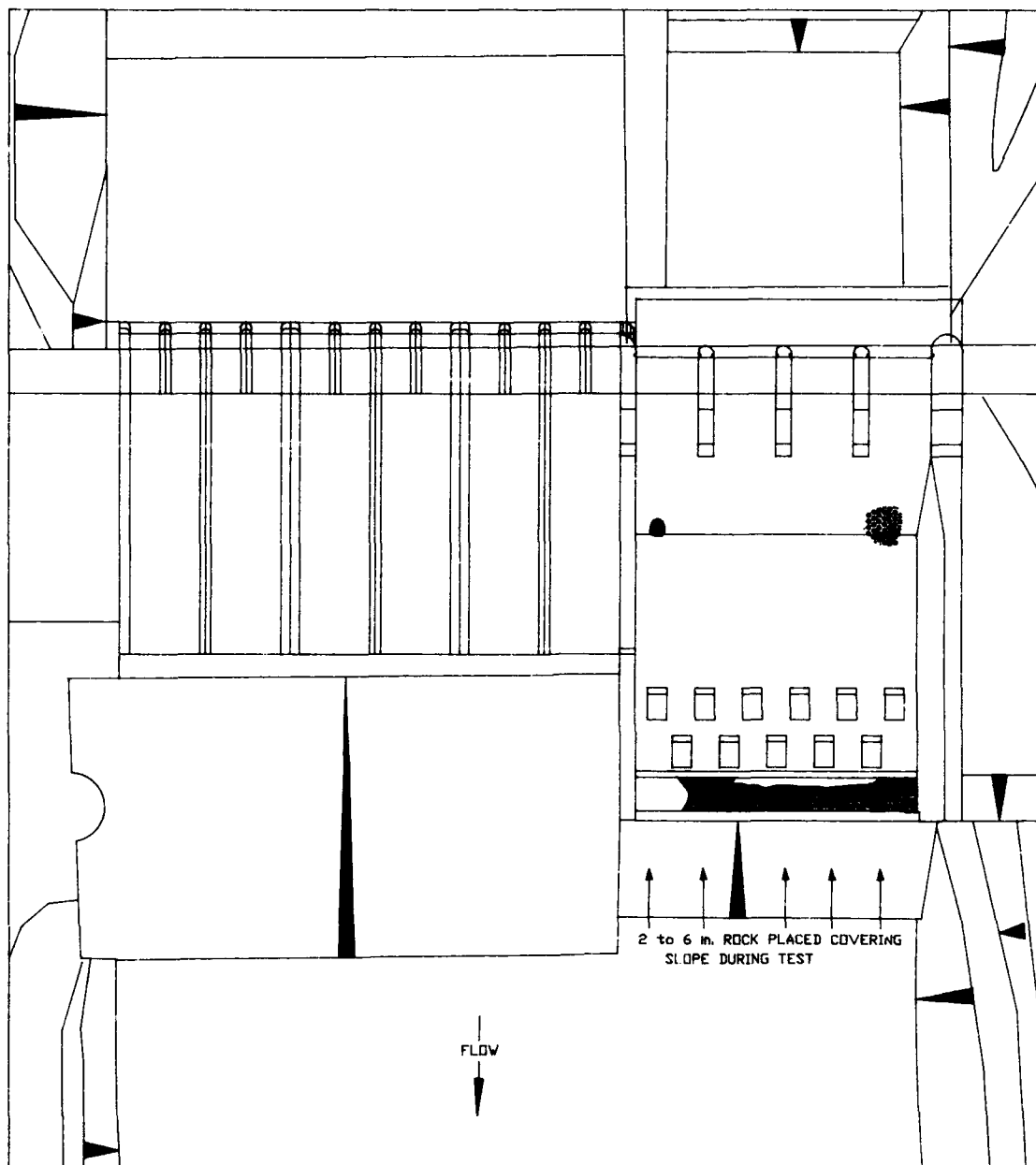
POWERHOUSE 29,000 CFS

TAINTER GATES OPEN 6.2 FT

5 GATES OPEN IN POWERHOUSE

POOL EL. 736.7, TAILWATER EL. 664.5

TYPE 5 ROCK TRAP



### STONE DISPLACEMENT TEST NO. 22

DISCHARGE :

SPILLWAY 32,000 CFS

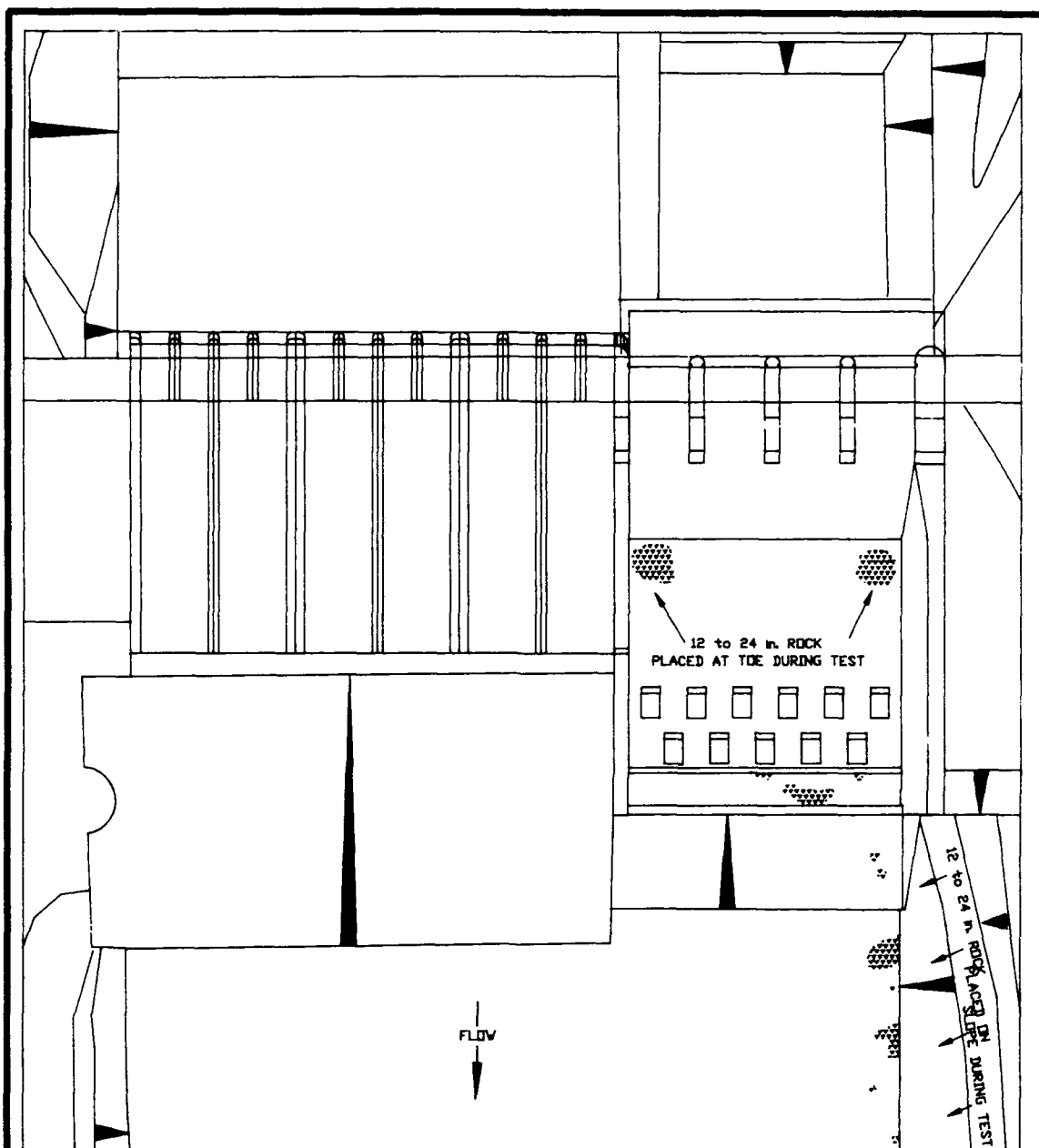
POWERHOUSE 29,000 CFS

TAINTER GATES OPEN 6.2 FT

5 GATES OPEN IN POWERHOUSE

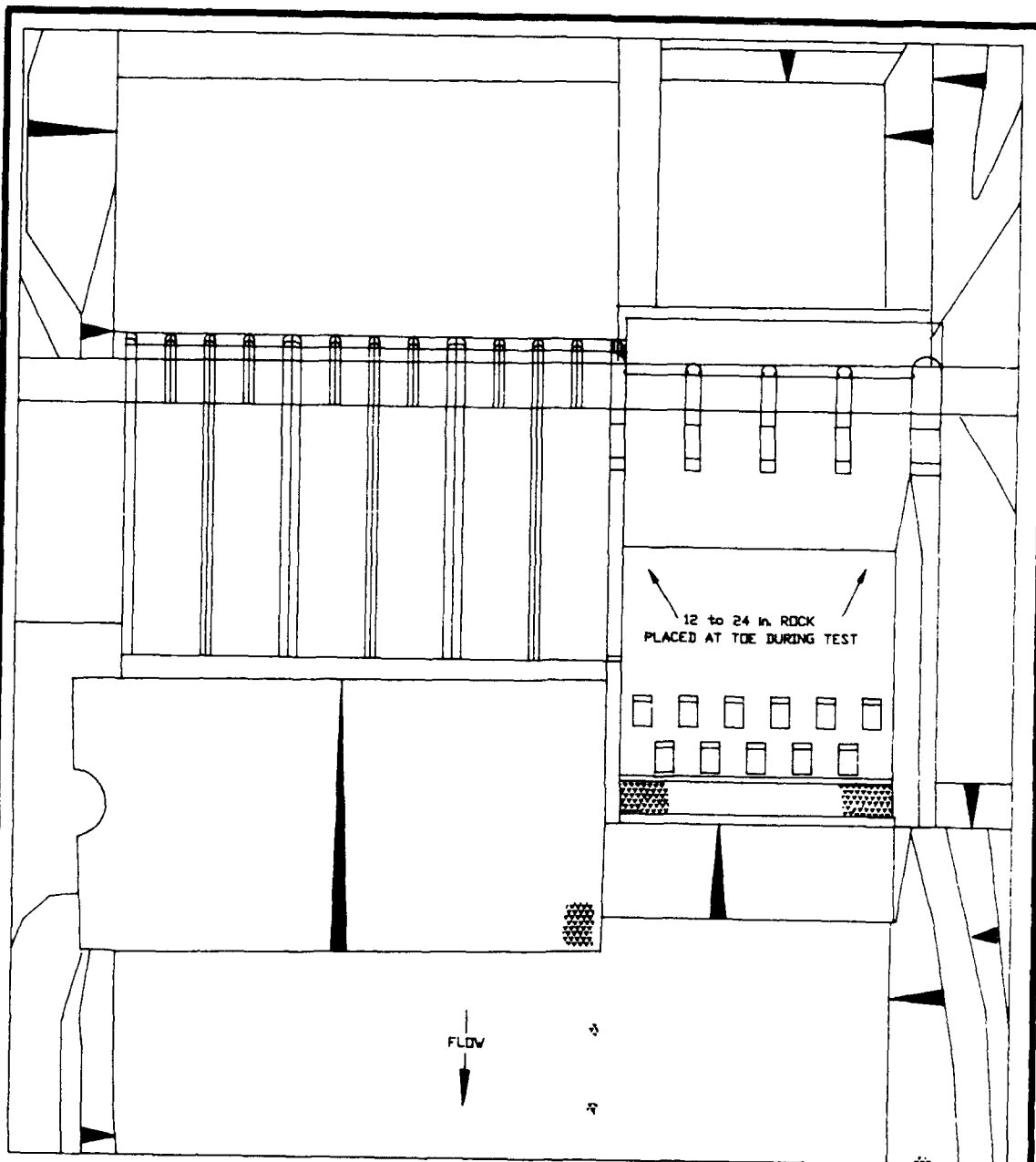
POOL EL 736.7, TAILWATER EL 664.5

TYPE 5 ROCK TRAP



**STONE DISPLACEMENT TEST NO. 5**  
 DISCHARGE :  
 SPILLWAY 32,000 CFS  
 POWERHOUSE 29,000 CFS  
 TAINTER GATES OPEN 6.2 FT  
 5 GATES OPEN IN POWERHOUSE  
 POOL EL 736.7, TAILWATER EL 664.5  
 TYPE 5 ROCK TRAP





# **STONE DISPLACEMENT TEST NO. 6**

DISCHARGE :

SPILLWAY 200,000 CFS

POWERHOUSE 29,000 CFS

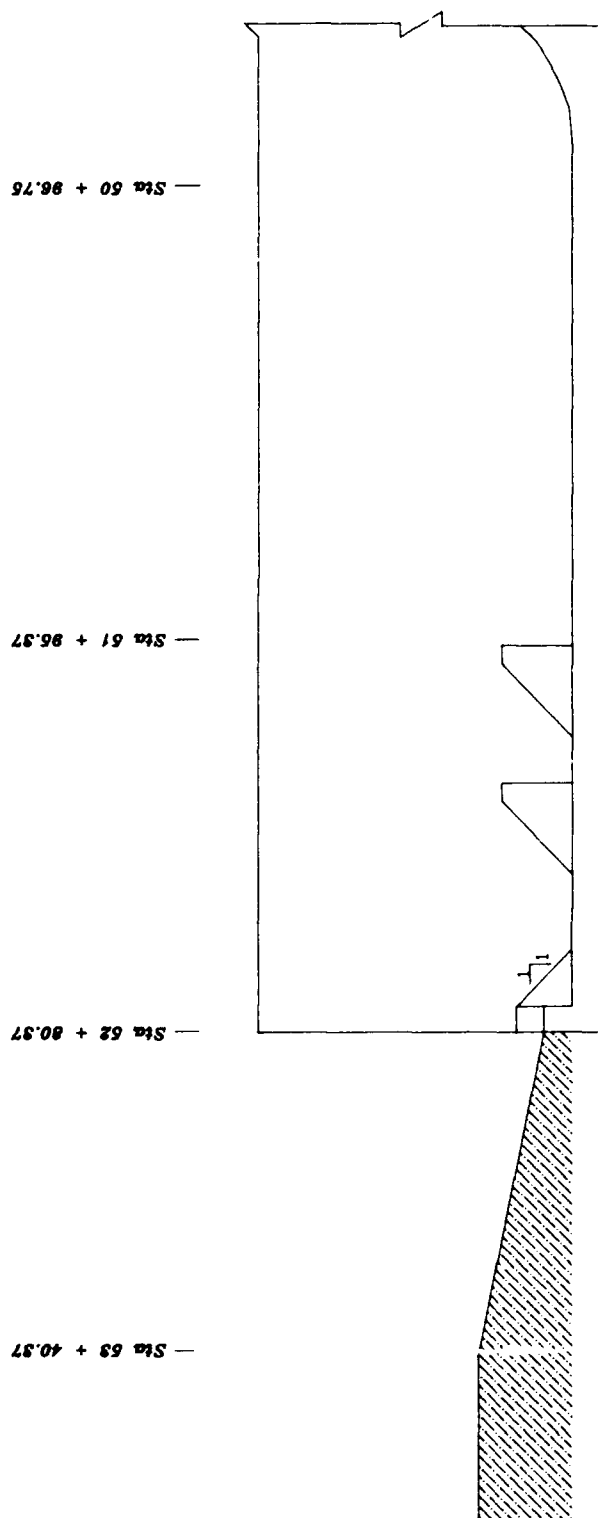
TAINTER GATES FULL OPEN

5 GATES OPEN IN POWERHOUSE

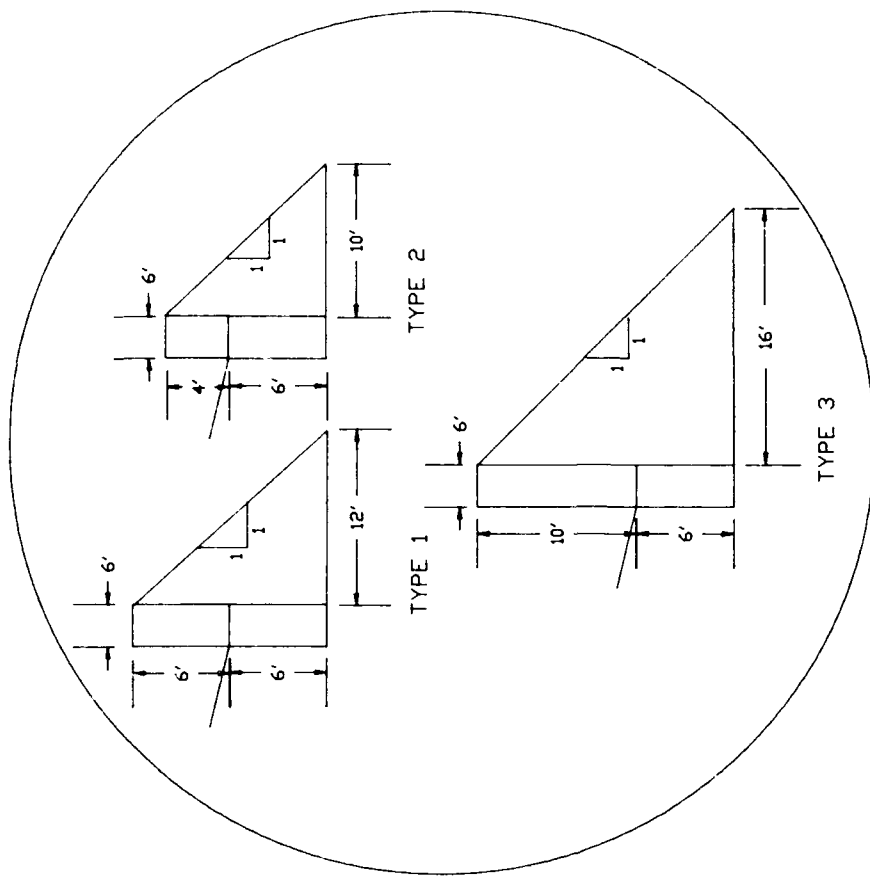
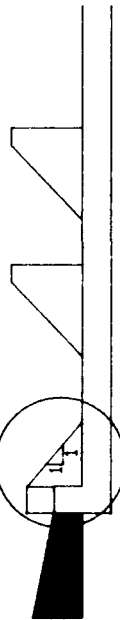
POOL EL 742.0, TAILWATER EL 665.0

TYPE 5 ROCK TRAP

# MODIFIED END SILL

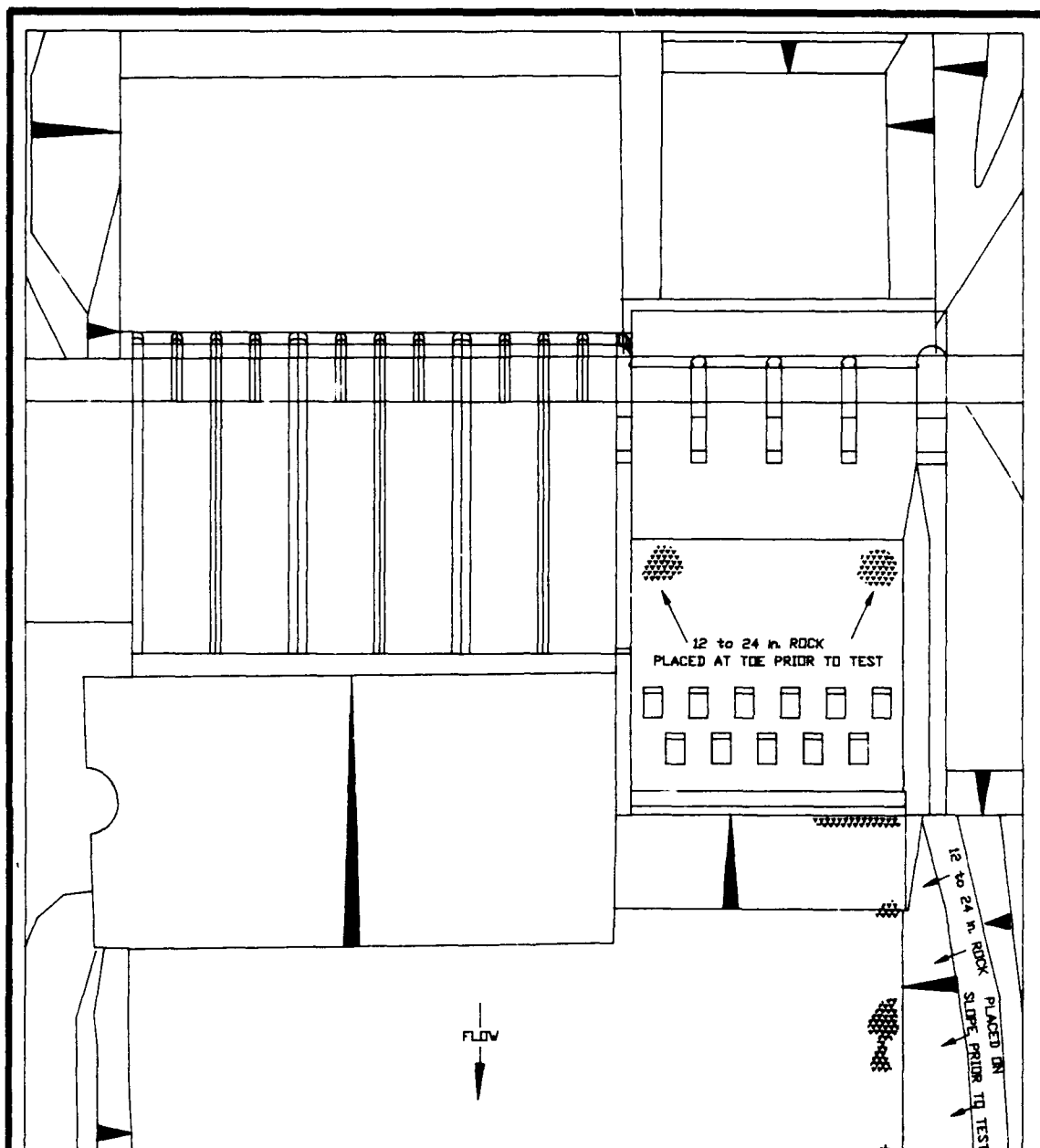


DETAIL 2



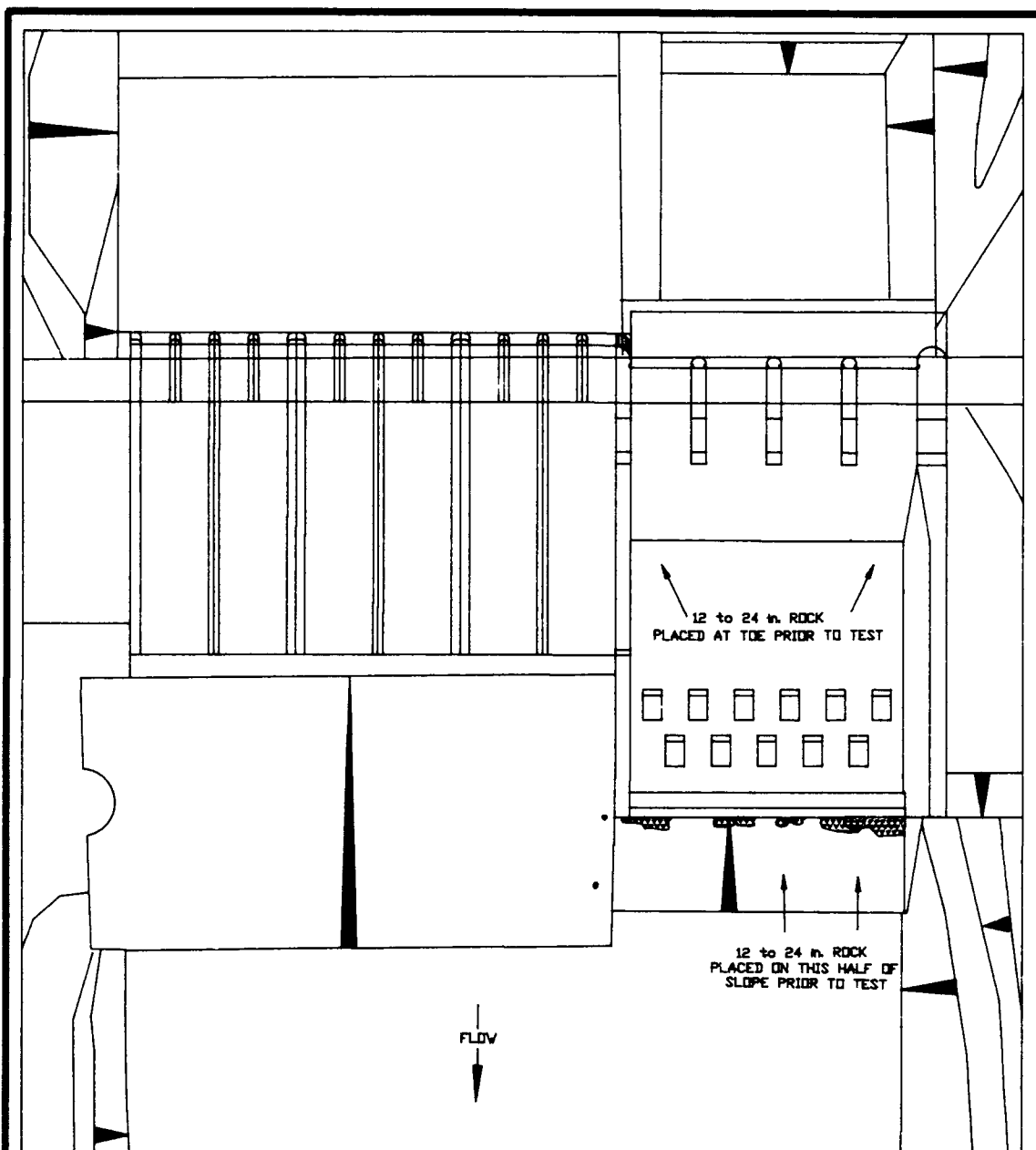
DETAIL 2

**BACK SLOPING END SILL DETAIL**  
TYPES 1, 2, AND 3



### STONE DISPLACEMENT TEST NO. 9

DISCHARGE :  
 SPILLWAY 32,000 CFS  
 POWERHOUSE 29,000 CFS  
 TAINTER GATES OPEN 6.2 FT  
 5 GATES OPEN IN POWERHOUSE  
 POOL EL 736.7, TAILWATER EL 664.5  
 TYPE 1 END SILL



### STONE DISPLACEMENT TEST NO. 10

DISCHARGE :

SPILLWAY 200,000 CFS

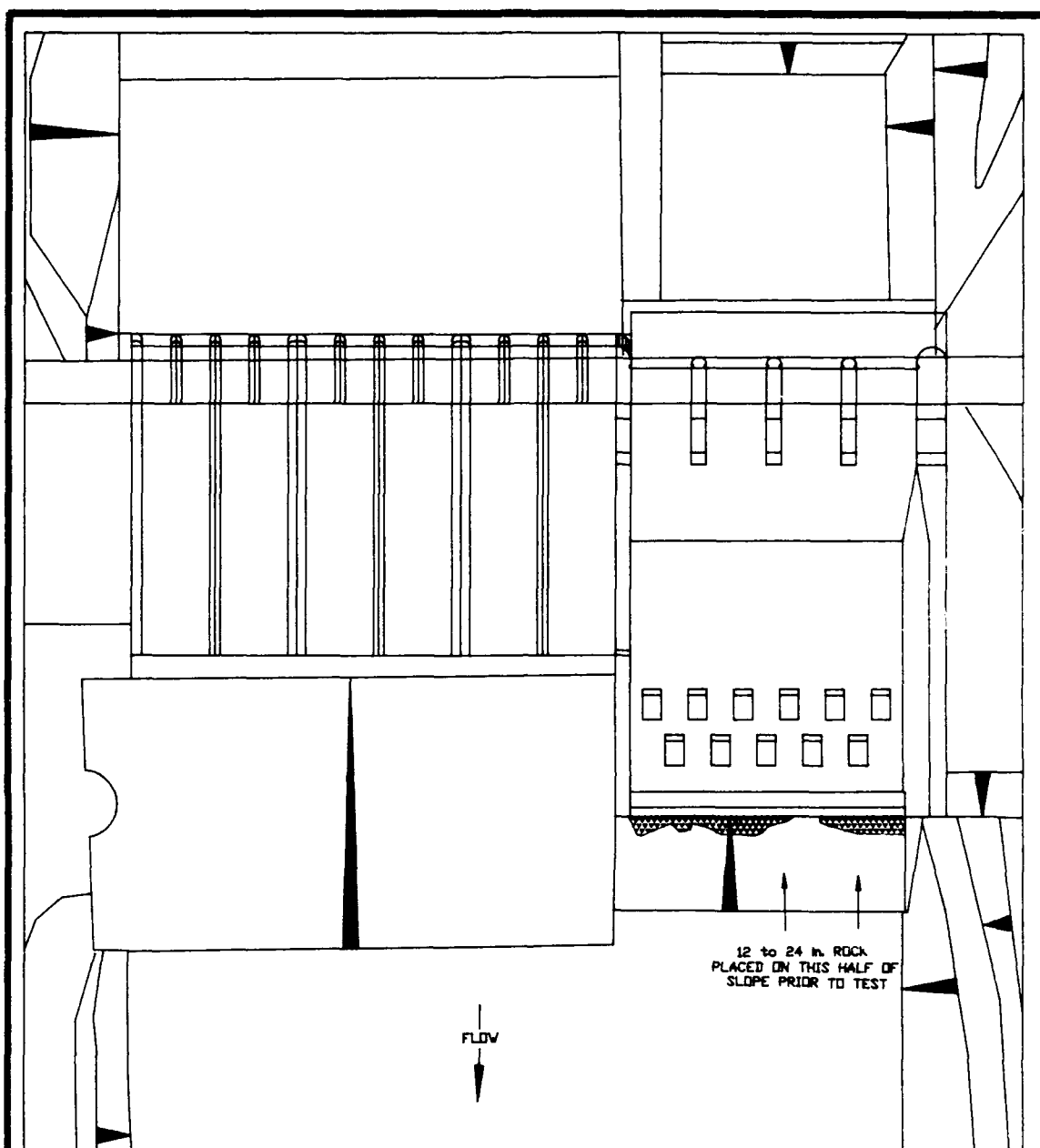
POWERHOUSE 29,000 CFS

TANTIER GATES FULL OPEN

5 GATES OPEN IN POWERHOUSE

POOL EL 742.0, TAILWATER EL 675.0

TYPE 1 END SILL



### STONE DISPLACEMENT TEST NO. 11

DISCHARGE :

SPILLWAY 32,000 CFS

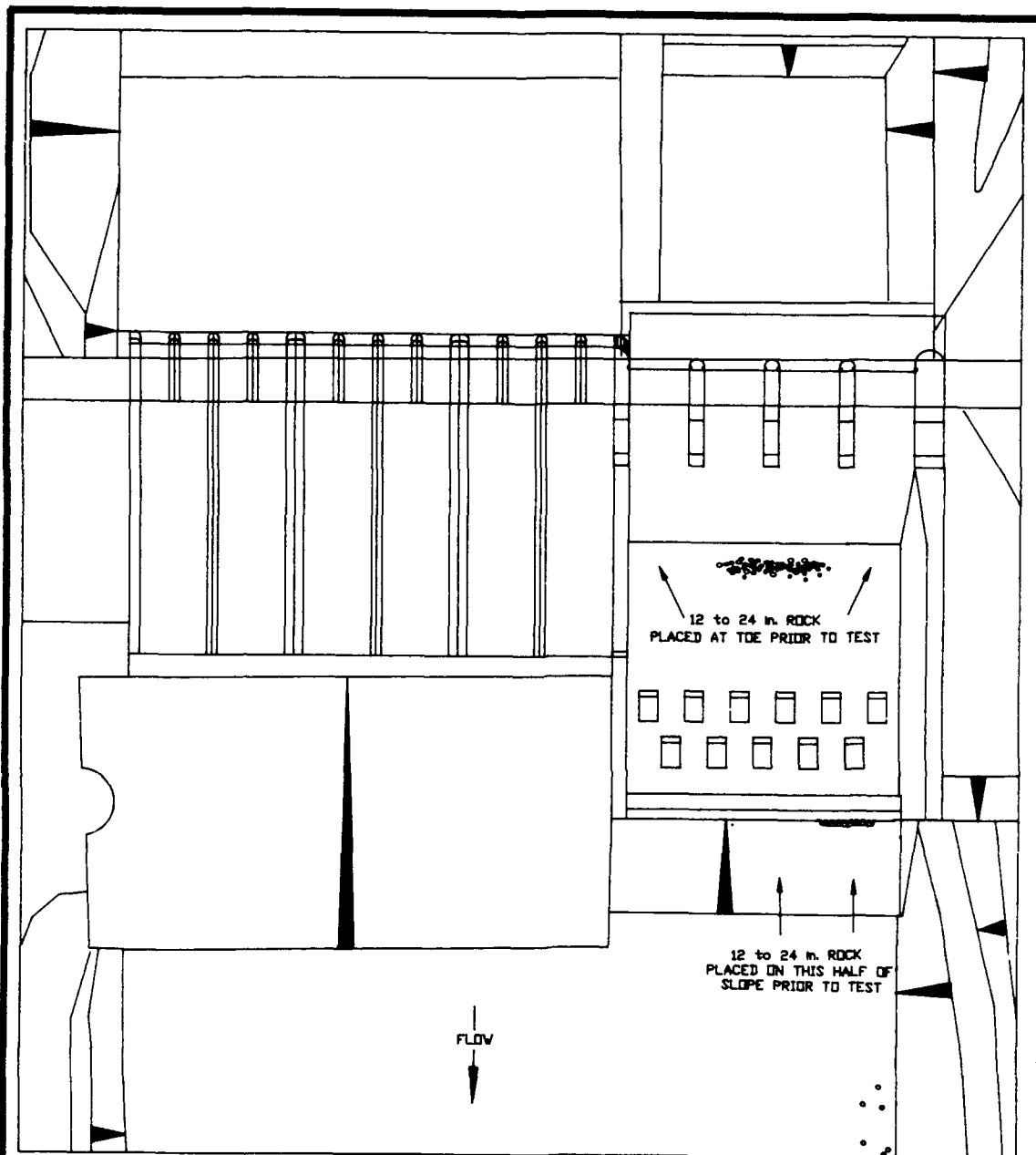
POWERHOUSE 29,000 CFS

TAINTER GATES OPEN 6.2 FT

5 GATES OPEN IN POWERHOUSE

POOL EL 736.7, TAILWATER EL 664.5

TYPE 1 END SILL



### STONE DISPLACEMENT TEST NO. 12

DISCHARGE :

SPILLWAY 41,000 CFS

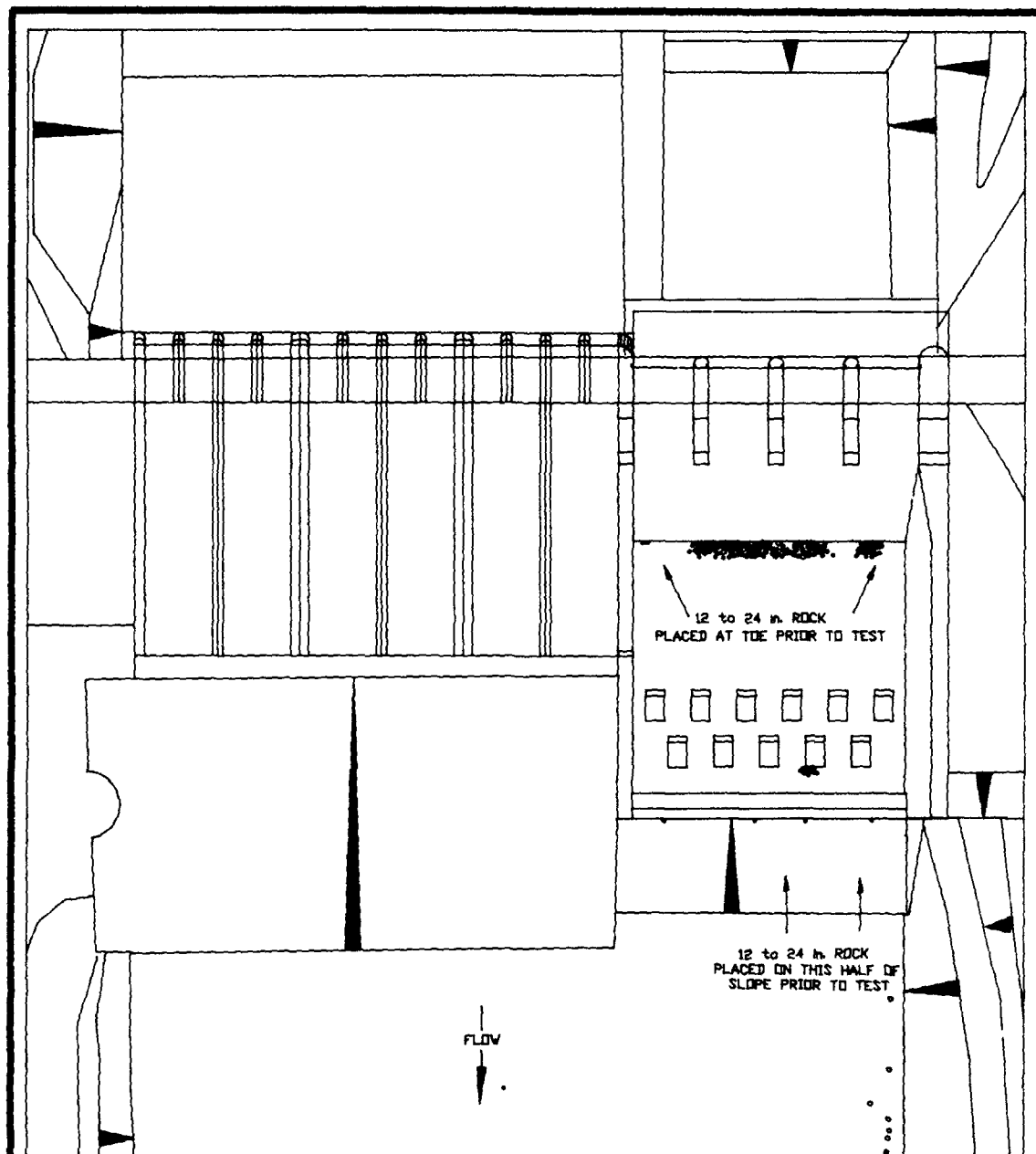
POWERHOUSE 29,000 CFS

TAINTER GATES OPEN 7.7 FT

5 GATES OPEN IN POWERHOUSE

POOL EL 738.3, TAILWATER EL 665.4

TYPE 2 END SILL



### STONE DISPLACEMENT TEST NO. 13

DISCHARGE :

SPILLWAY 61,000 CFS

POWERHOUSE 29,000 CFS

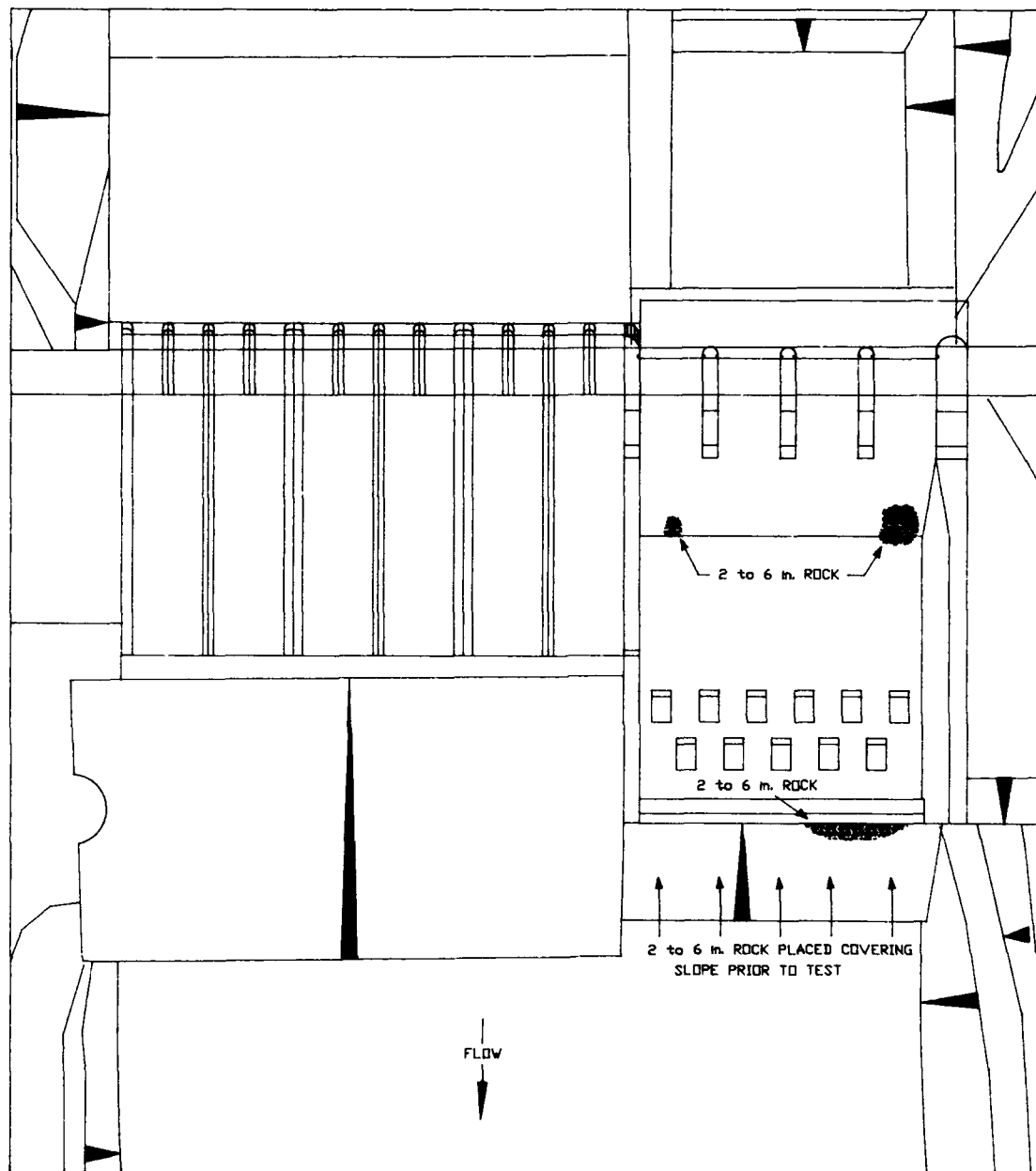
TAINTER GATES OPEN 11.2 FT

5 GATES OPEN IN POWERHOUSE

POOL EL 740.0, TAILWATER EL 668.0

TYPE 2 END SILL





### STONE DISPLACEMENT TEST NO. 18

DISCHARGE:

SPILLWAY 32,000 CFS

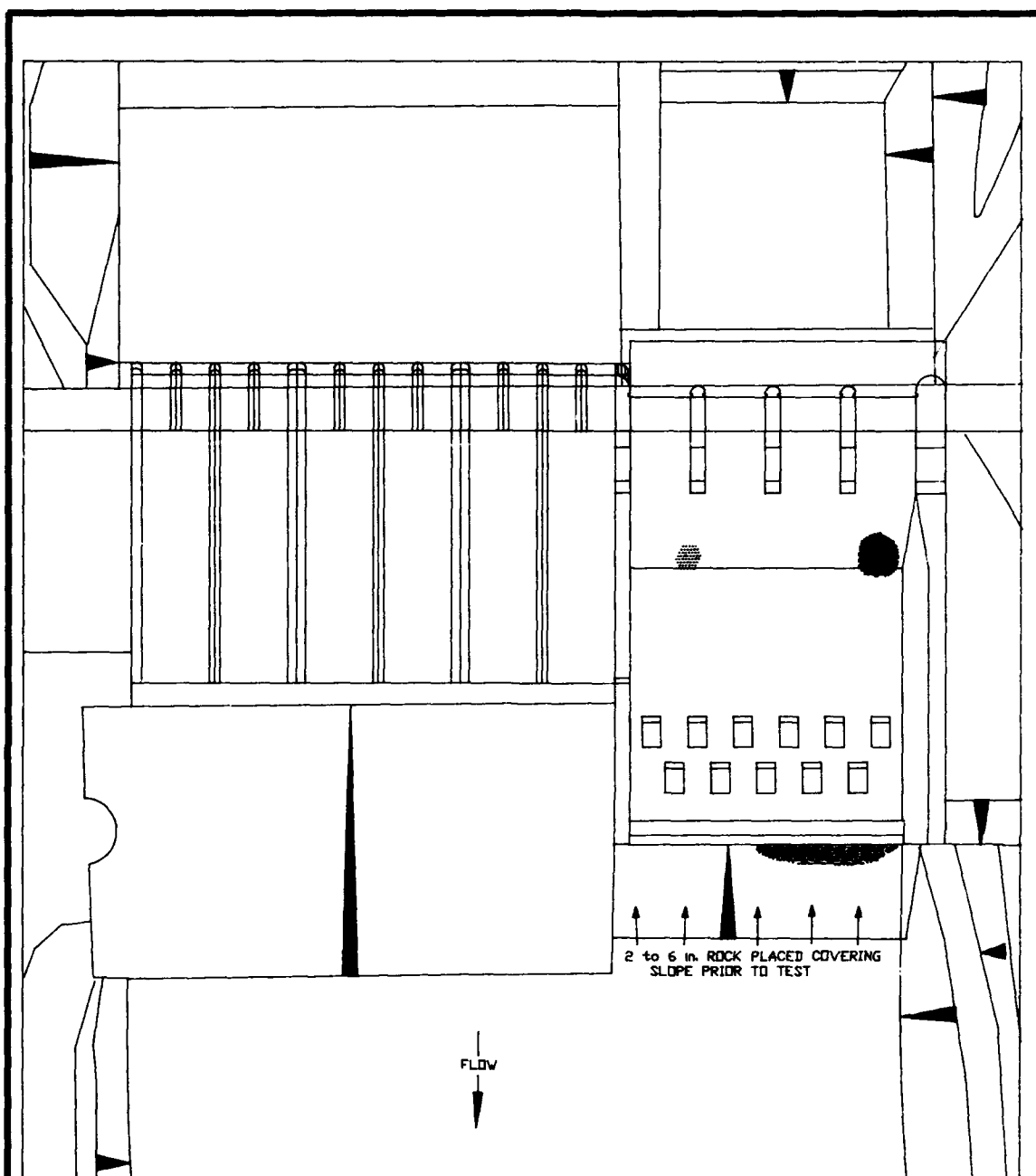
POWERHOUSE 29,000 CFS

TAINTER GATES OPEN 6.2 FT

5 GATES OPEN IN POWERHOUSE

POOL EL 737.7, TAILWATER EL 664.5

TYPE 3 END SILL



# **STONE DISPLACEMENT TEST NO. 19**

DISCHARGE :

SPILLWAY 32,000 CFS

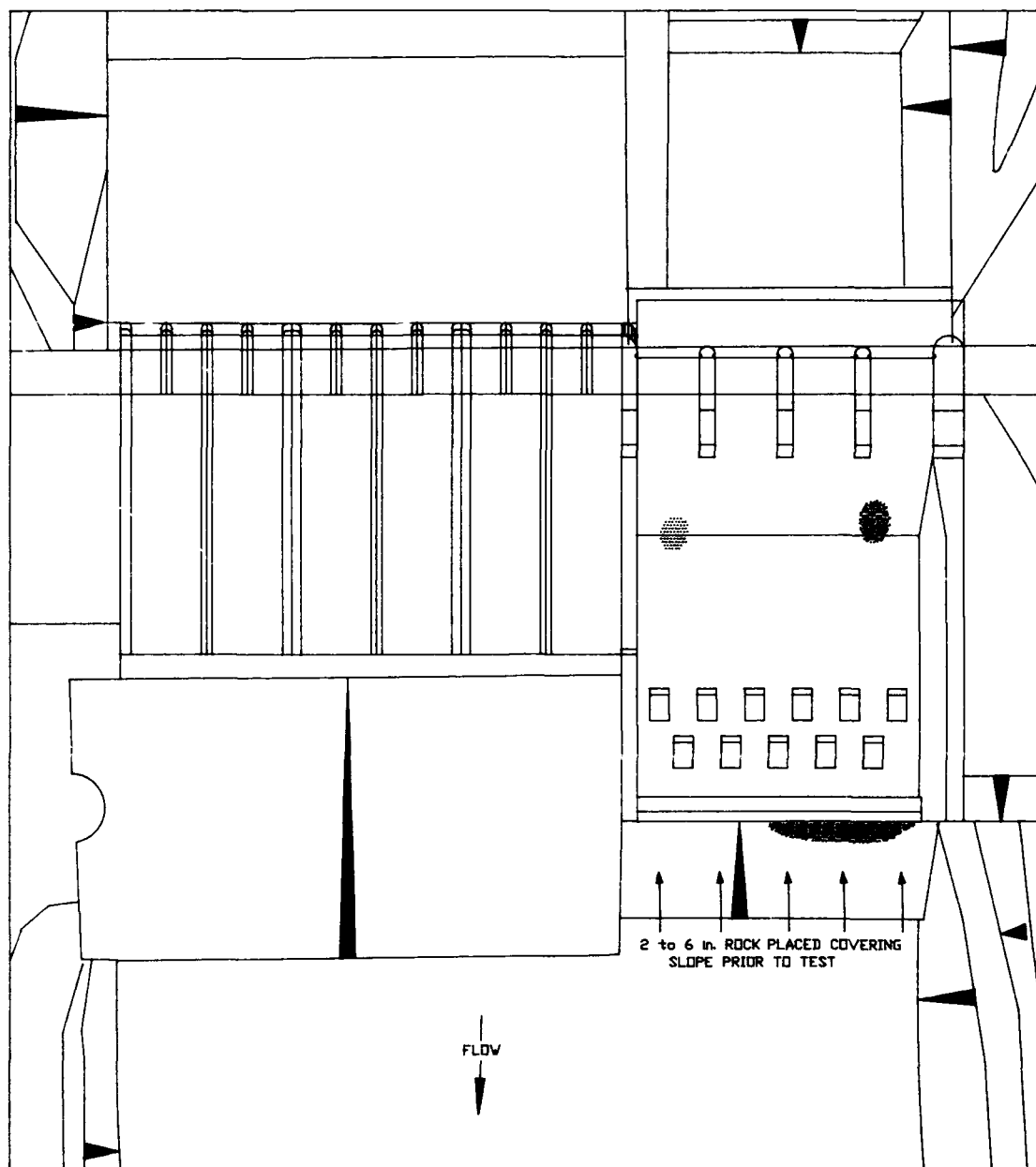
POWERHOUSE 29,000 CFS

TANTER GATES OPEN 6.2 FT

5 GATES OPEN IN POWERHOUSE

POOL EL 736.7, TAILWATER EL 664.5

TYPE 3 END SILL



### STONE DISPLACEMENT TEST NO. 20

DISCHARGE :

SPILLWAY 32,000 CFS

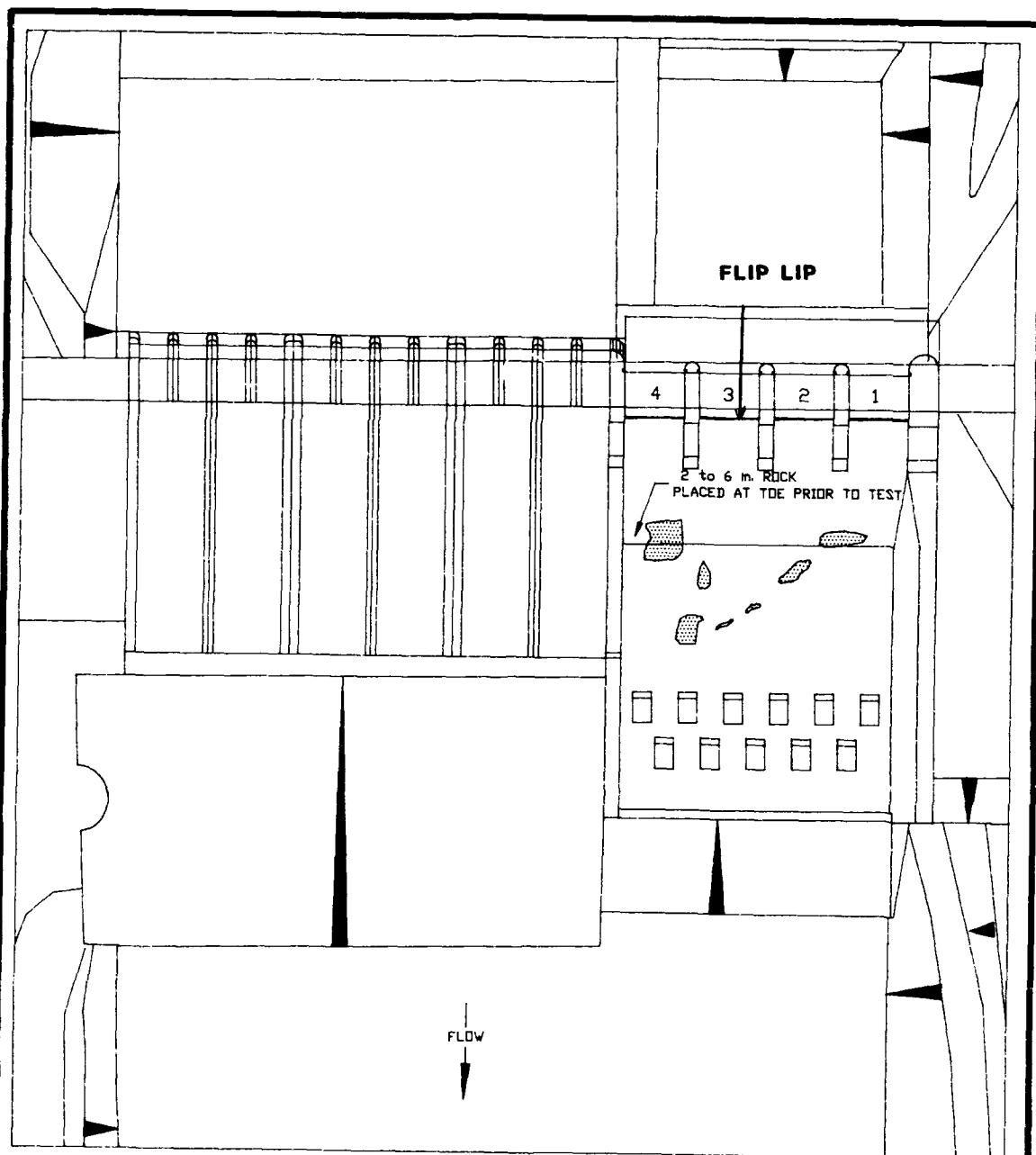
POWERHOUSE 29,000 CFS

TAINTER GATES OPEN 6.2 FT

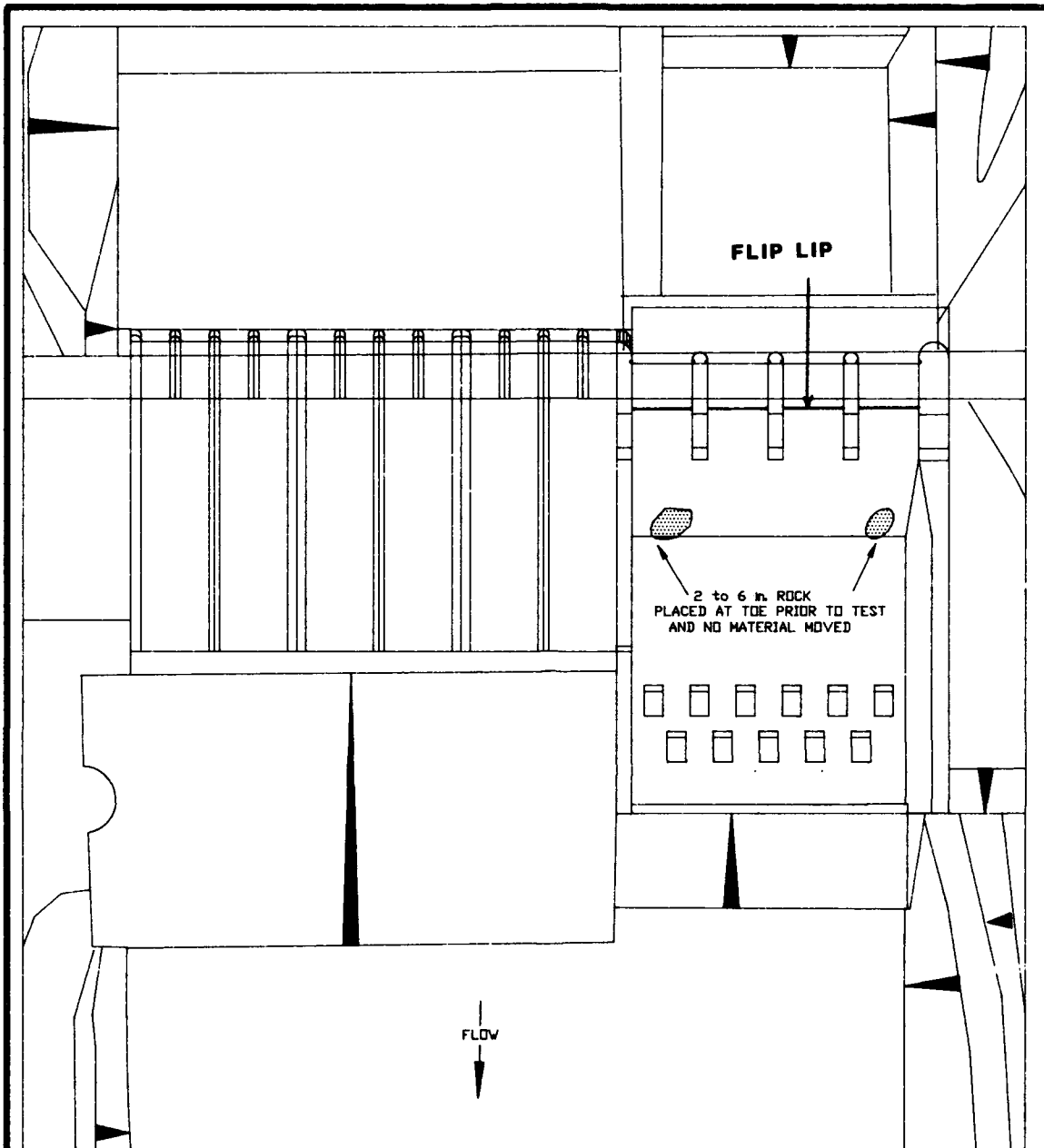
5 GATES OPEN IN POWERHOUSE

POOL EL 736.7, TAILWATER EL 664.5

TYPE 3 END SILL



**STONE DISPLACEMENT TEST NO. 23**  
 TAINTER GATE NO. 4 OPEN 1 FT  
 POWERHOUSE GATES CLOSED  
 POOL EL 730.0, TAILWATER EL 662.0



### STONE DISPLACEMENT TEST NO. 24

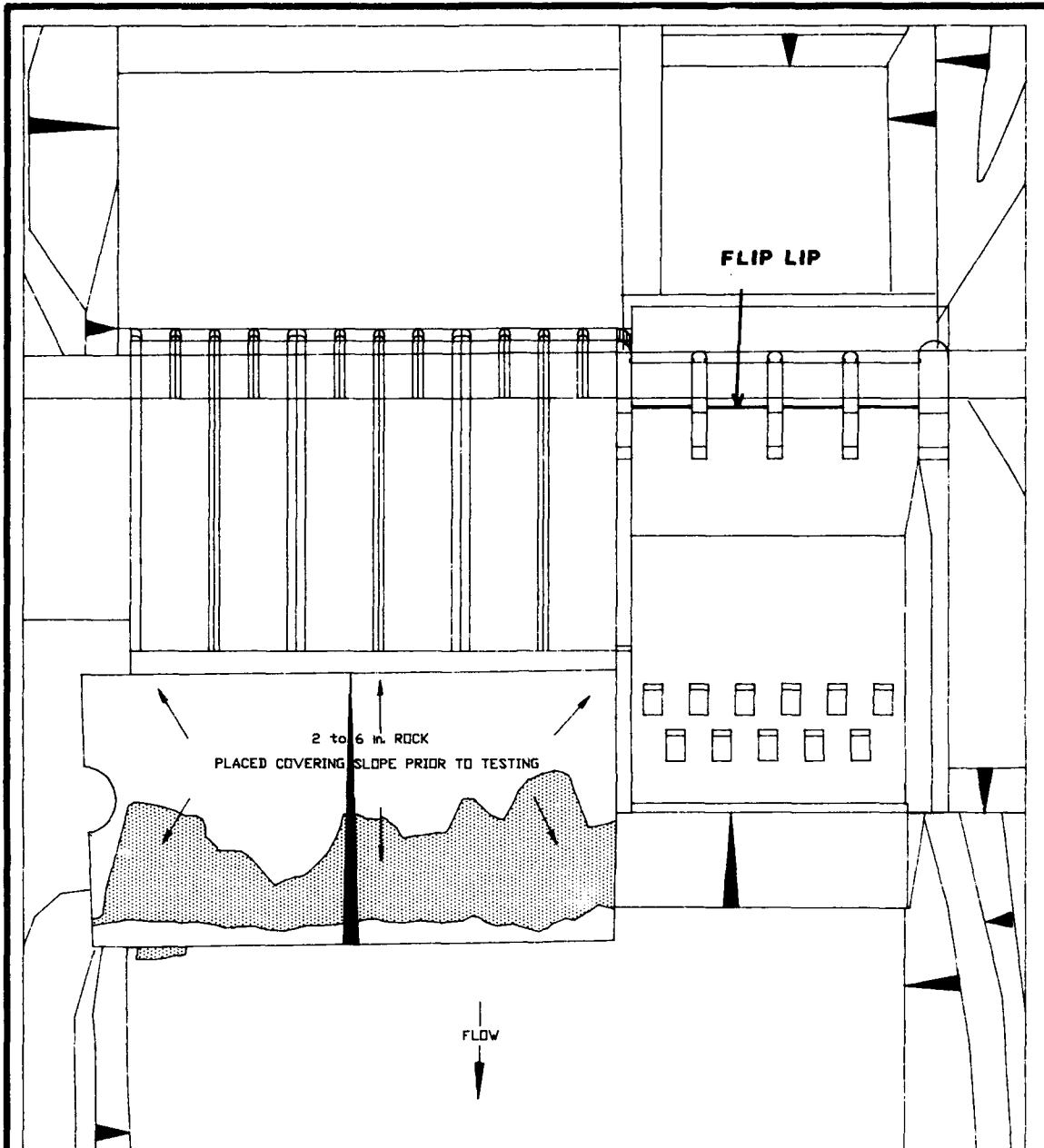
DISCHARGE :

POWERHOUSE 65,000 CFS

ALL TAINTER GATES FULLY CLOSED

ALL GATES OPEN IN POWERHOUSE

POOL EL 706.0, TAILWATER EL 662.0



### STONE DISPLACEMENT TEST NO. 25

DISCHARGE :

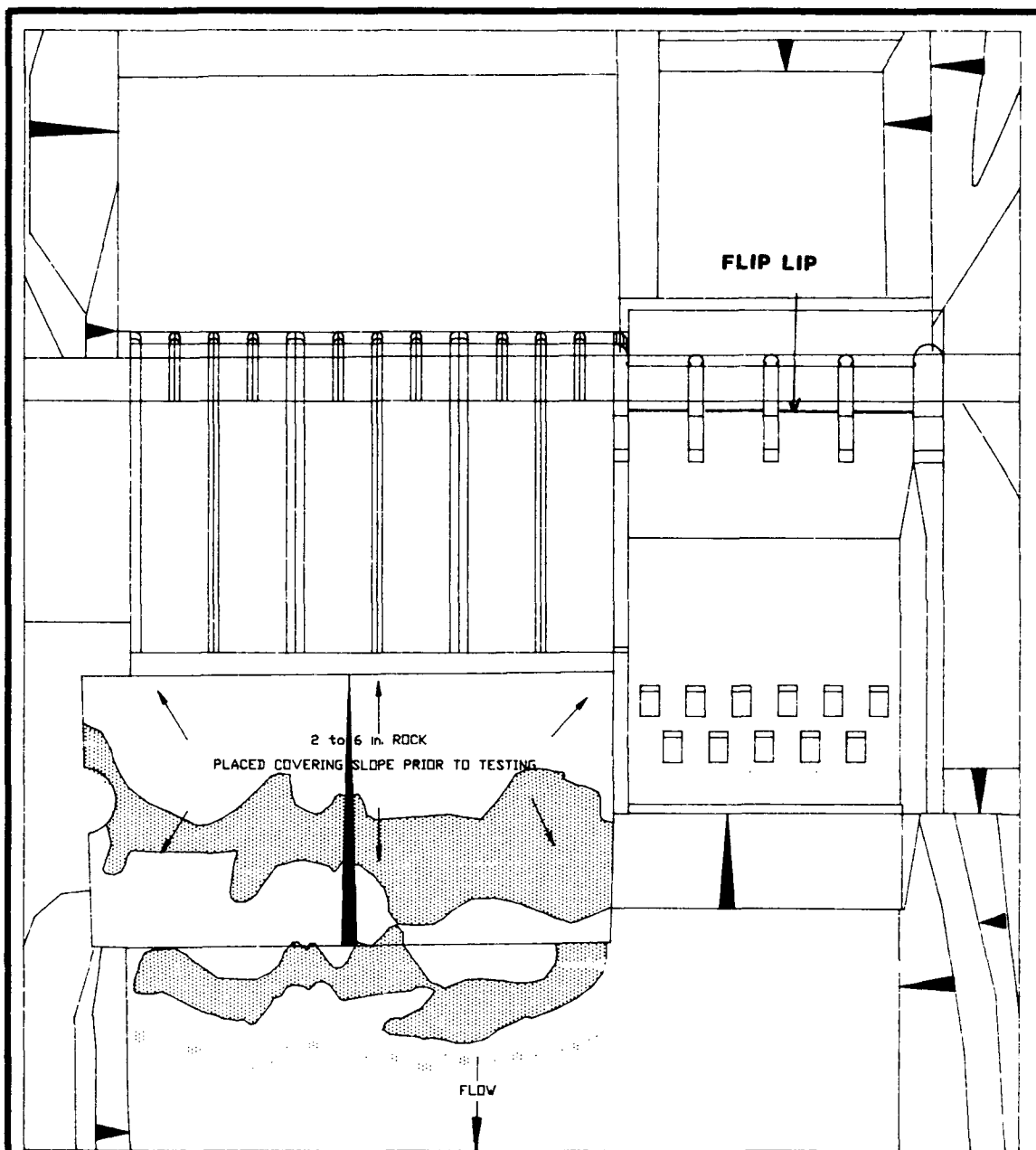
POWERHOUSE 35,000 CFS

SPILLWAY 45,000 CFS

TANTER GATES OPEN 7.3 FT

ALL GATES OPEN IN POWERHOUSE

POOL EL 739.6, TAILWATER EL 665.0



# **STONE DISPLACEMENT TEST NO. 26**

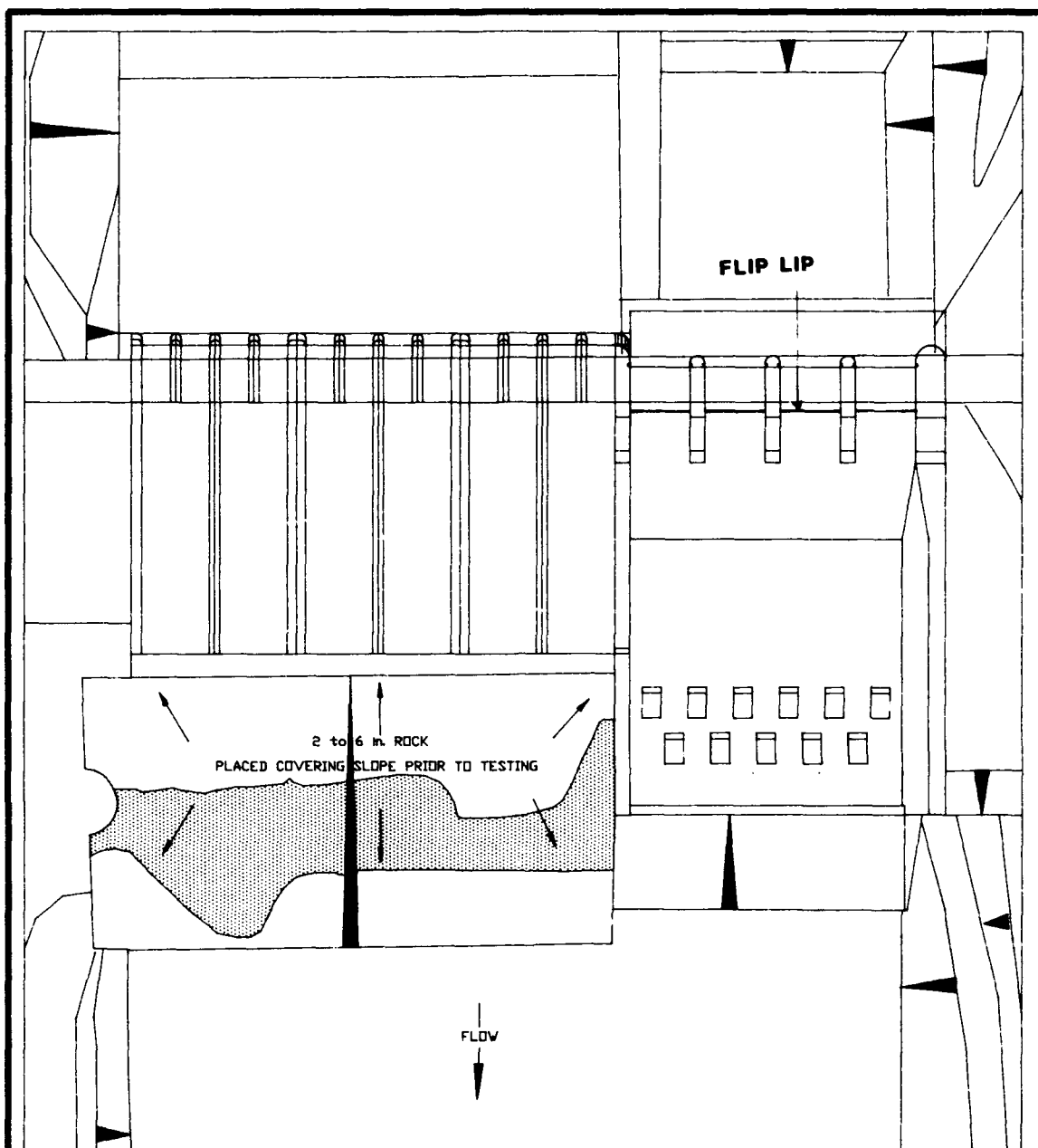
DISCHARGE :

POWERHOUSE 65,000 CFS

ALL TAINTER GATES FULLY CLOSED

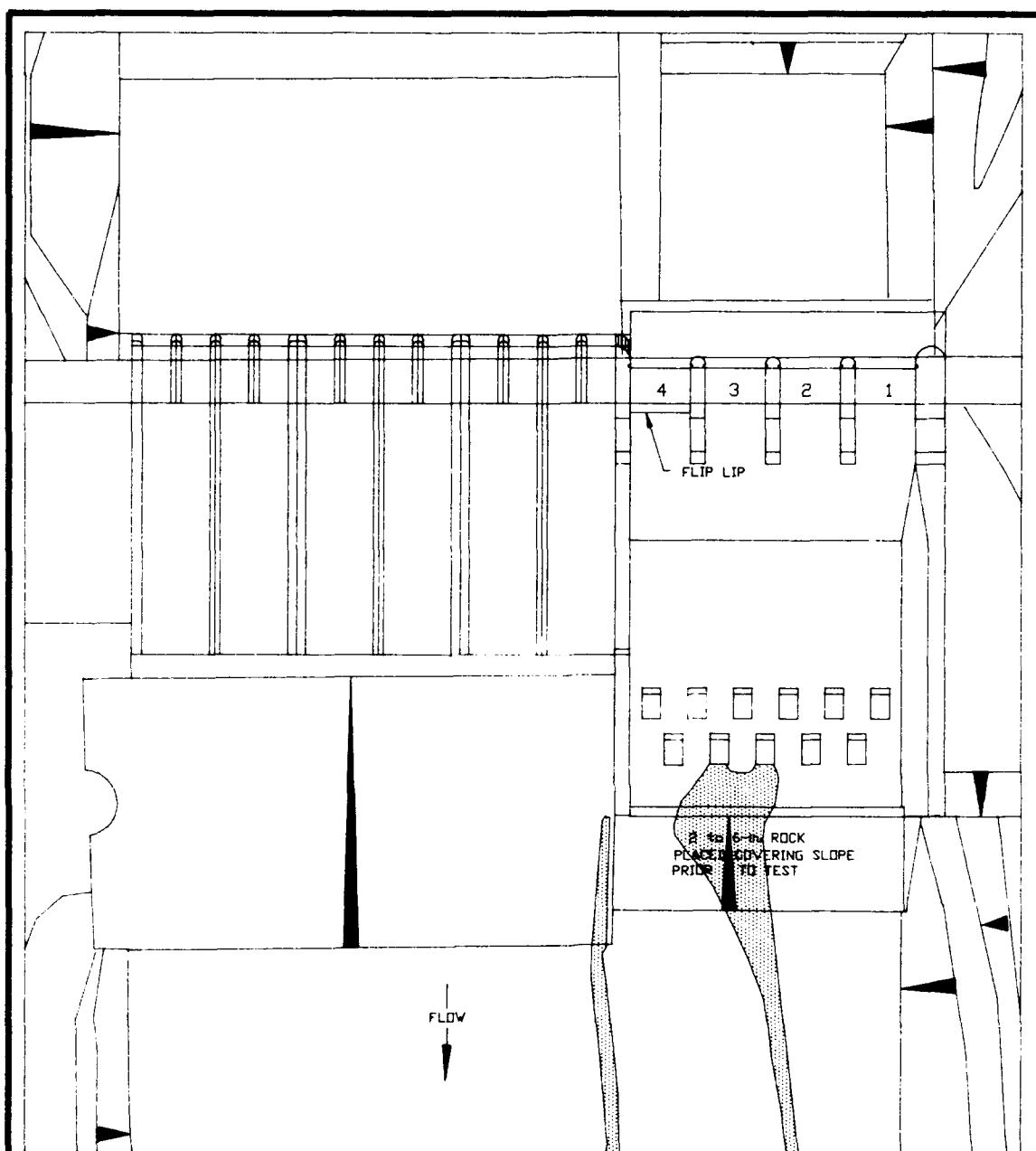
ALL GATES OPEN IN POWERHOUSE

POOL EL 706.0, TAILWATER EL 662.0



**STONE DISPLACEMENT TEST NO. 27**  
DISCHARGE :  
POWERHOUSE 29,000 CFS  
ALL TAINTER GATES FULLY CLOSED  
GATES 1-5 OPEN IN POWERHOUSE  
POOL EL 717.0, TAILWATER EL 663.0





# **STONE DISPLACEMENT TEST NO. 28**

DISCHARGE :

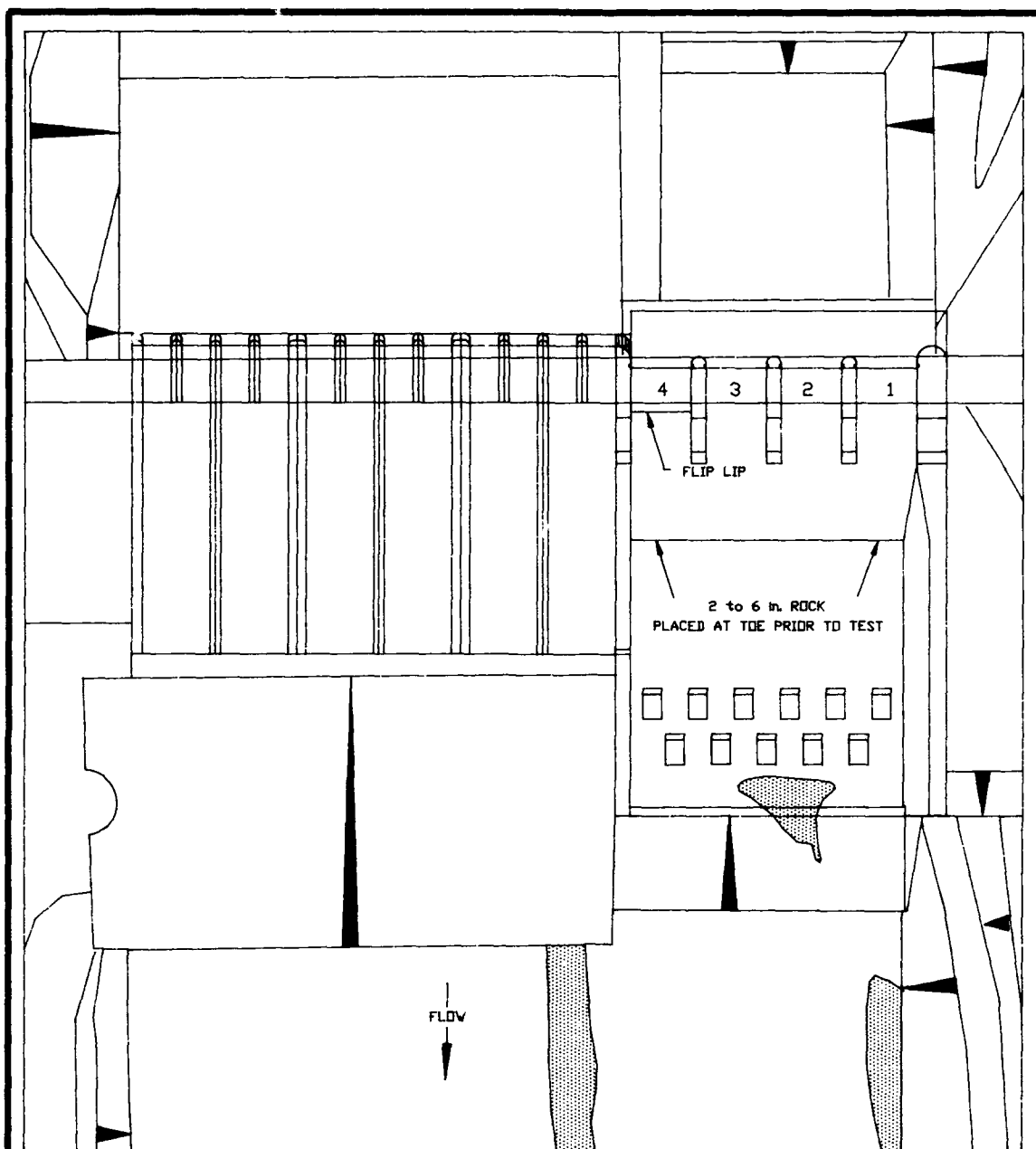
POWERHOUSE 29,000 CFS

SPILLWAY 32,000 CFS

FLIP LIP INSTALLED ON SPILLWAY CREST

IN SPILLWAY BAY NO. 4

POOL EL 737.7, TAILWATER EL 664.5



### STONE DISPLACEMENT TEST NO. 29

DISCHARGE :

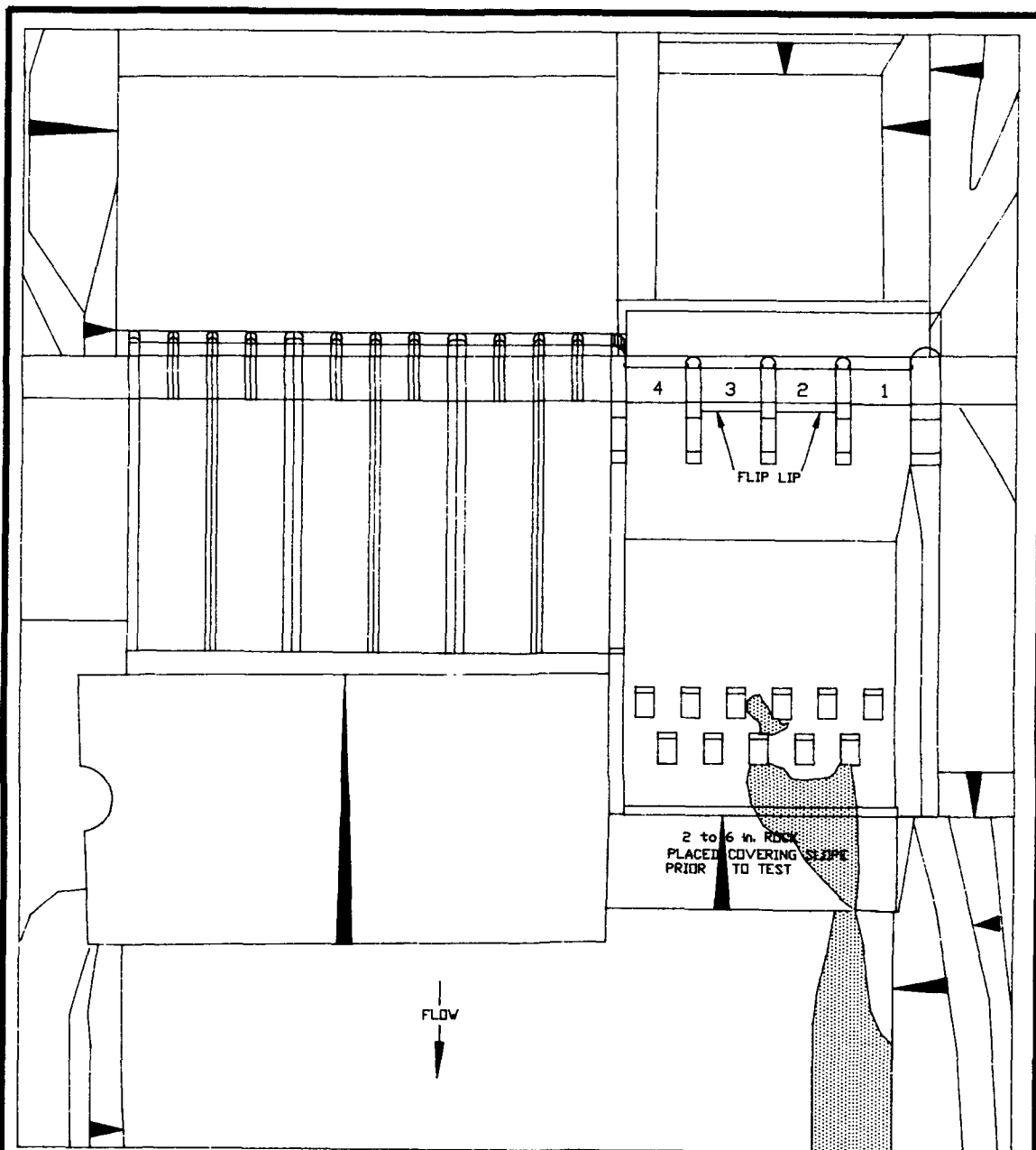
POWERHOUSE 29,000 CFS

SPILLWAY 32,000 CFS

FLIP LIP INSTALLED ON SPILLWAY CREST

IN SPILLWAY BAY NO. 4

POOL EL 737.7, TAILWATER EL 664.5



### STONE DISPLACEMENT TEST NO. 30

DISCHARGE :

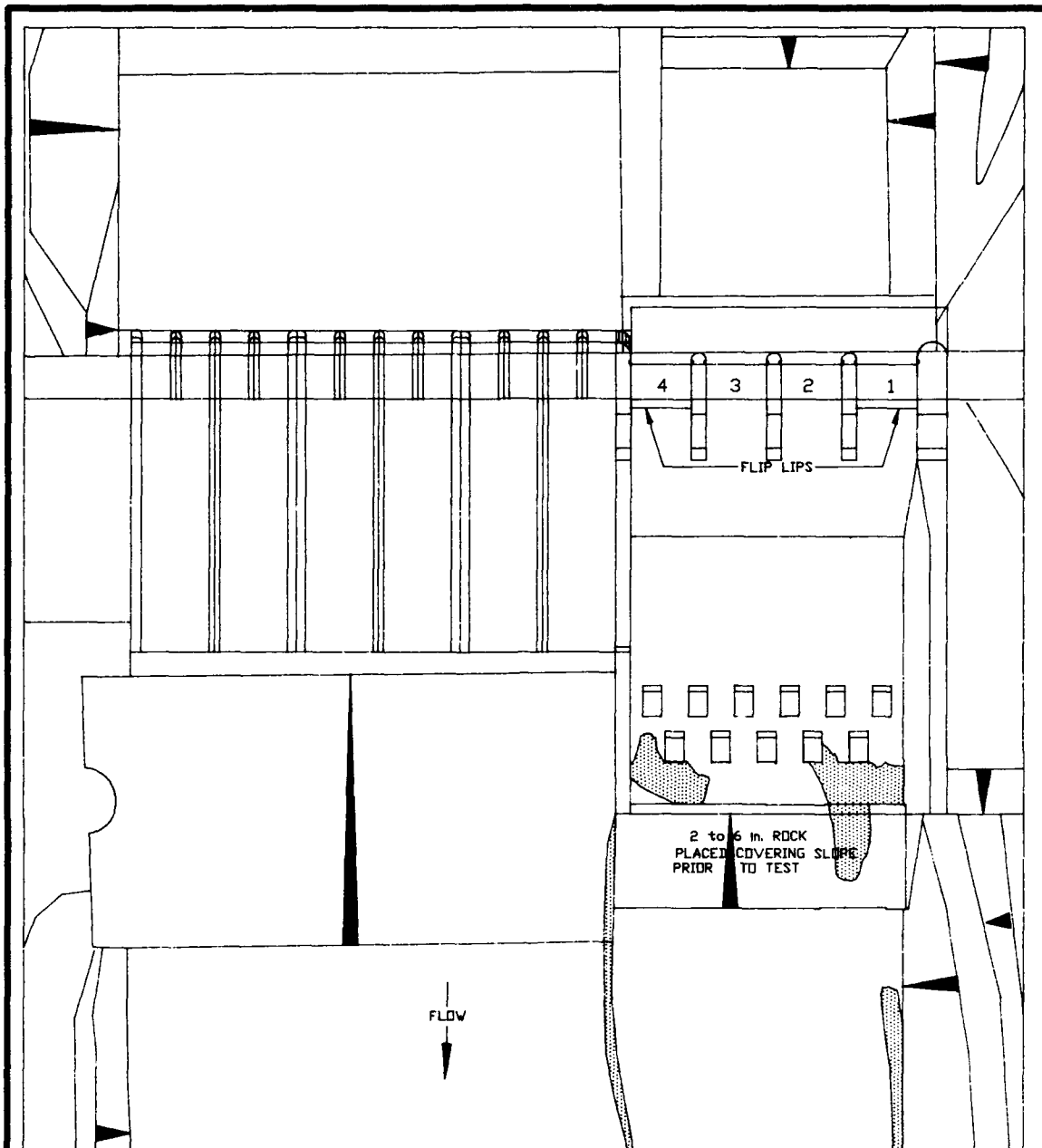
POWERHOUSE 29,000 CFS

SPILLWAY 32,000 CFS

FLIP LIPS INSTALLED ON SPILLWAY CREST

IN SPILLWAY BAYS NO. 2 AND 3

POOL EL 736.7, TAILWATER EL 664.5



### STONE DISPLACEMENT TEST NO. 31

DISCHARGE :

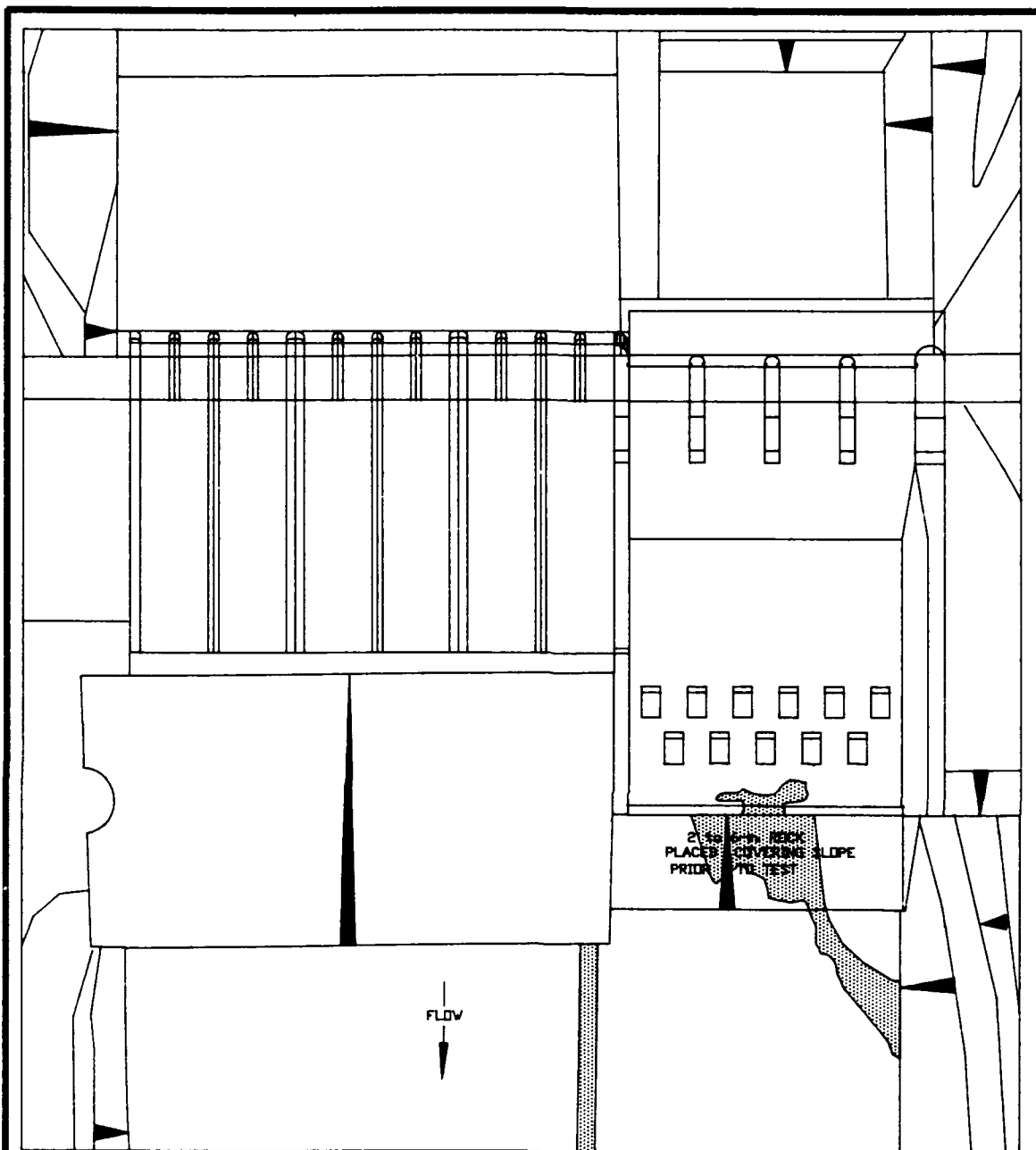
POWERHOUSE 29,000 CFS

SPILLWAY 32,000 CFS

FLIP LIPS INSTALLED ON SPILLWAY CREST

IN SPILLWAY BAYS 1 AND 4

POOL EL 736.7, TAILWATER EL 664.5



### STONE DISPLACEMENT TEST NO. 32

DISCHARGE :

POWERHOUSE 29,000 CFS

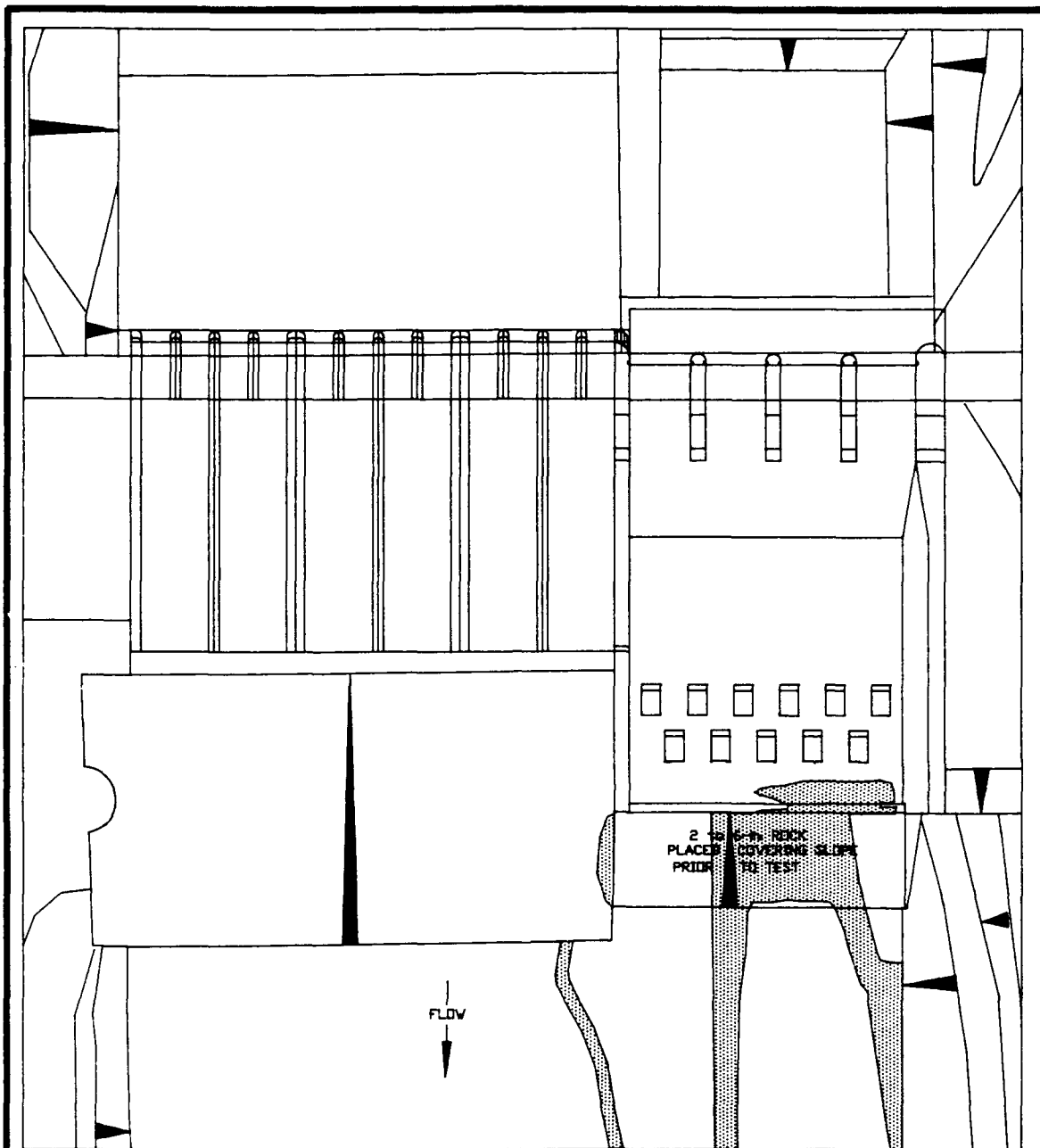
SPILLWAY 32,000 CFS

5 GATES OPEN IN POWERHOUSE

TAINTER GATES OPEN 6.2 FT.

POOL EL 736.7, TAILWATER EL 664.5

FLIP LIP REMOVED



**STONE DISPLACEMENT TEST NO. 33**

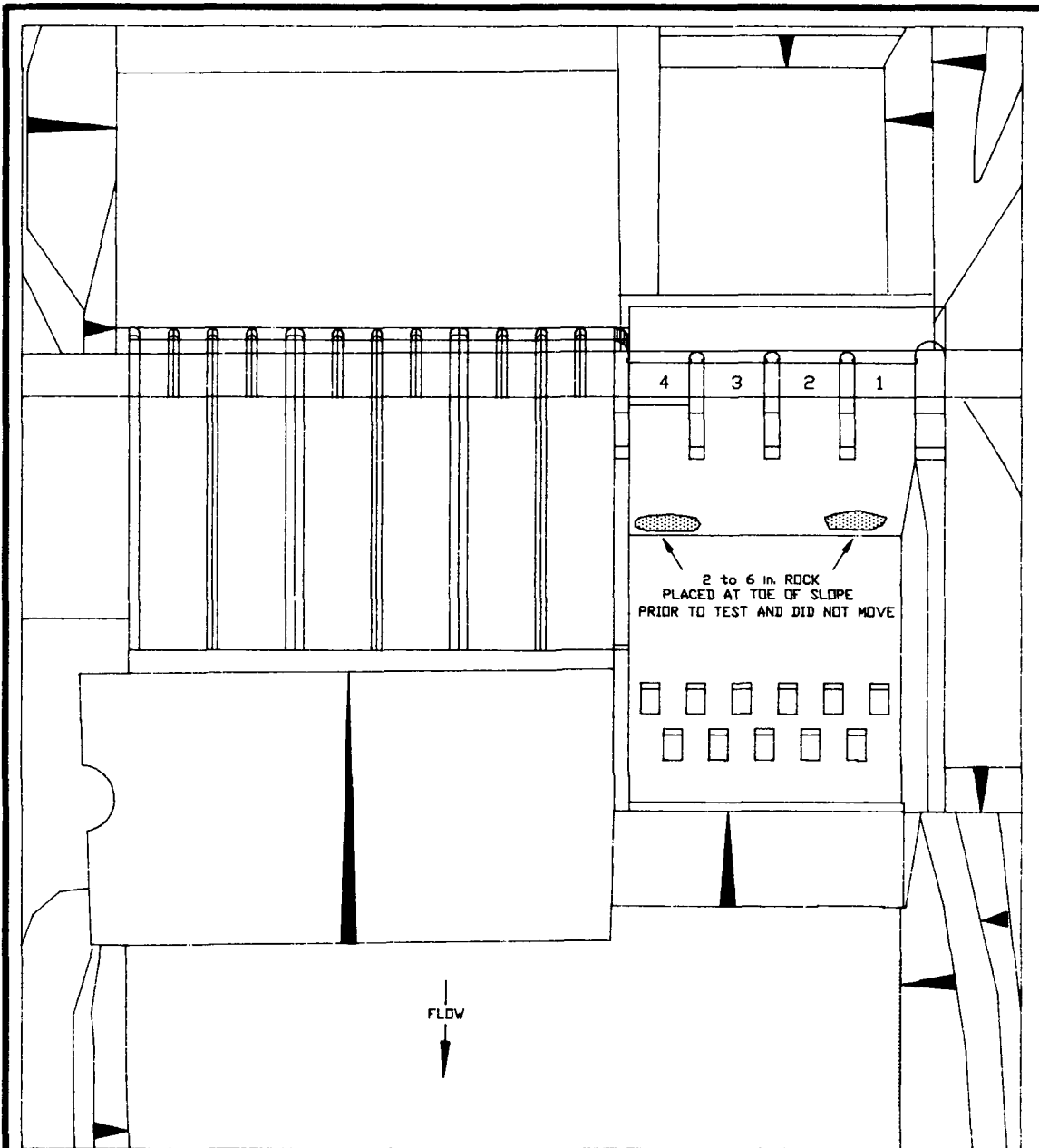
DISCHARGE :

POWERHOUSE 32,000 CFS

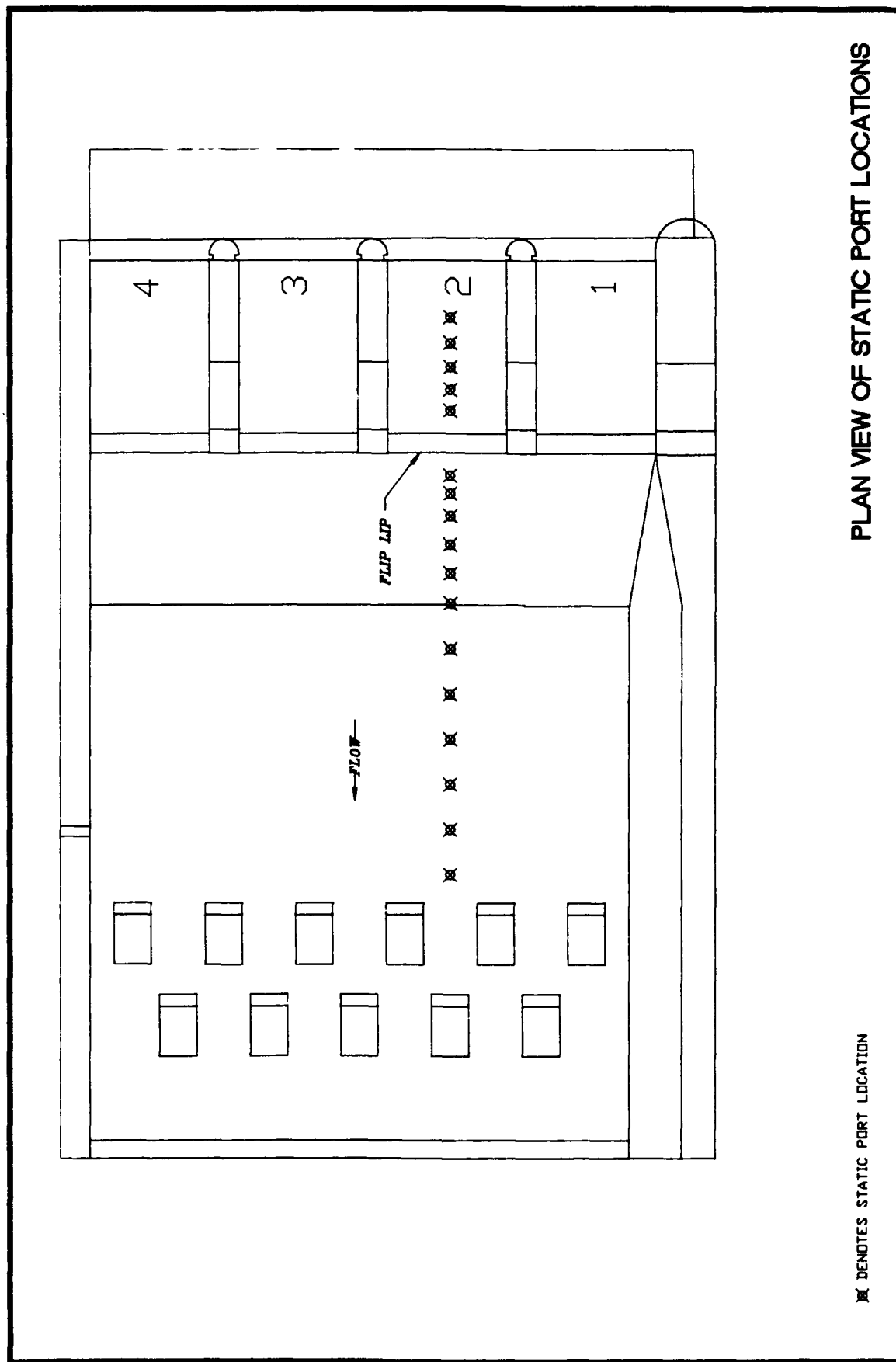
SPILLWAY 29,000 CFS

POOL EL 736.7, TAILWATER EL 664.5

FLIP LIP REMOVED



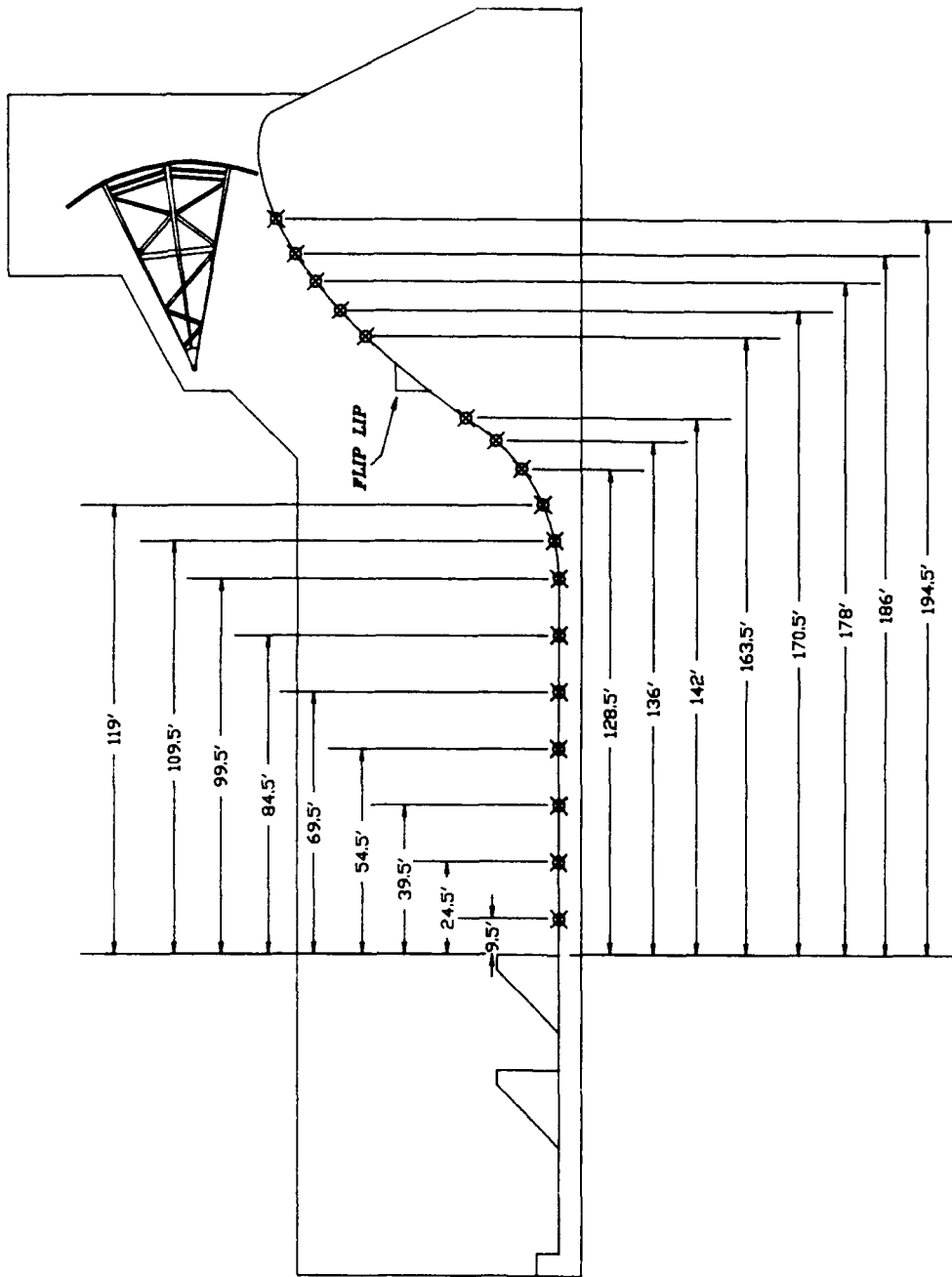
**STONE DISPLACEMENT TEST NO. 34**  
 ALL POWERHOUSE GATES CLOSED  
 TAINTER GATE NO. 4 OPEN 1 FT.  
 FLIP LIP ON CREST  
 IN SPILLWAY BAY NO. 4  
 POOL EL 706.0 TAILWATER EL 662.0



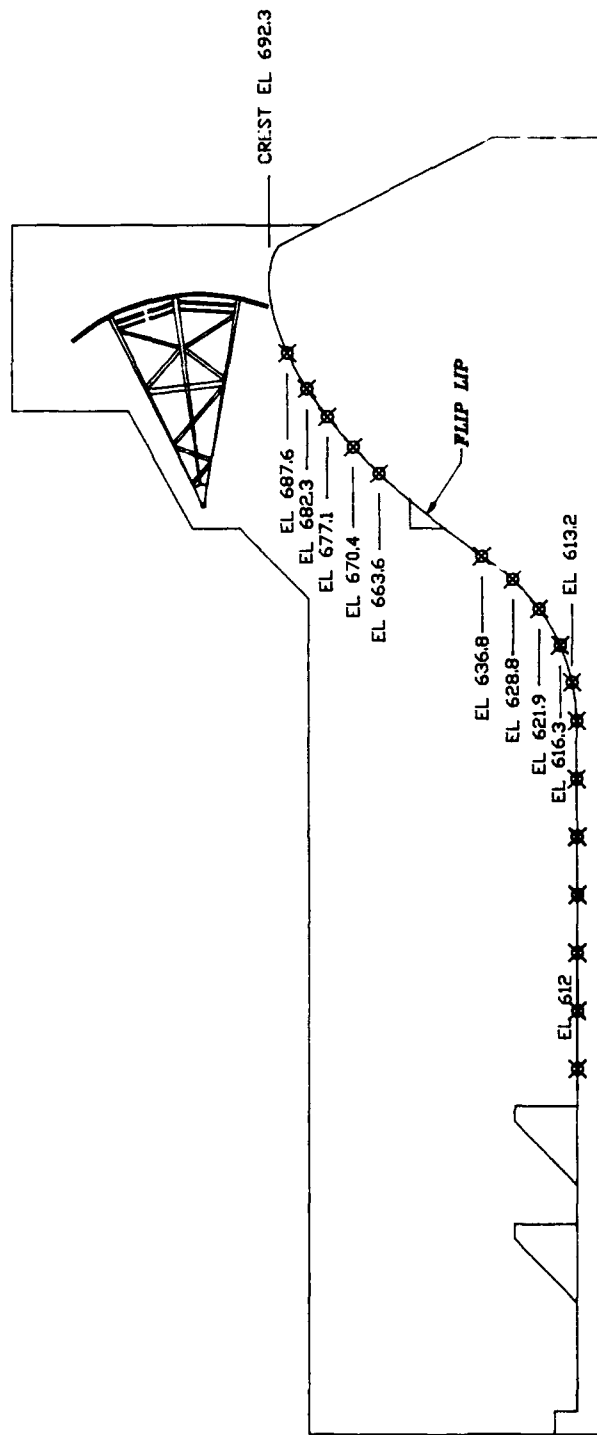
PLAN VIEW OF STATIC PORT LOCATIONS

X DENOTES STATIC PORT LOCATION

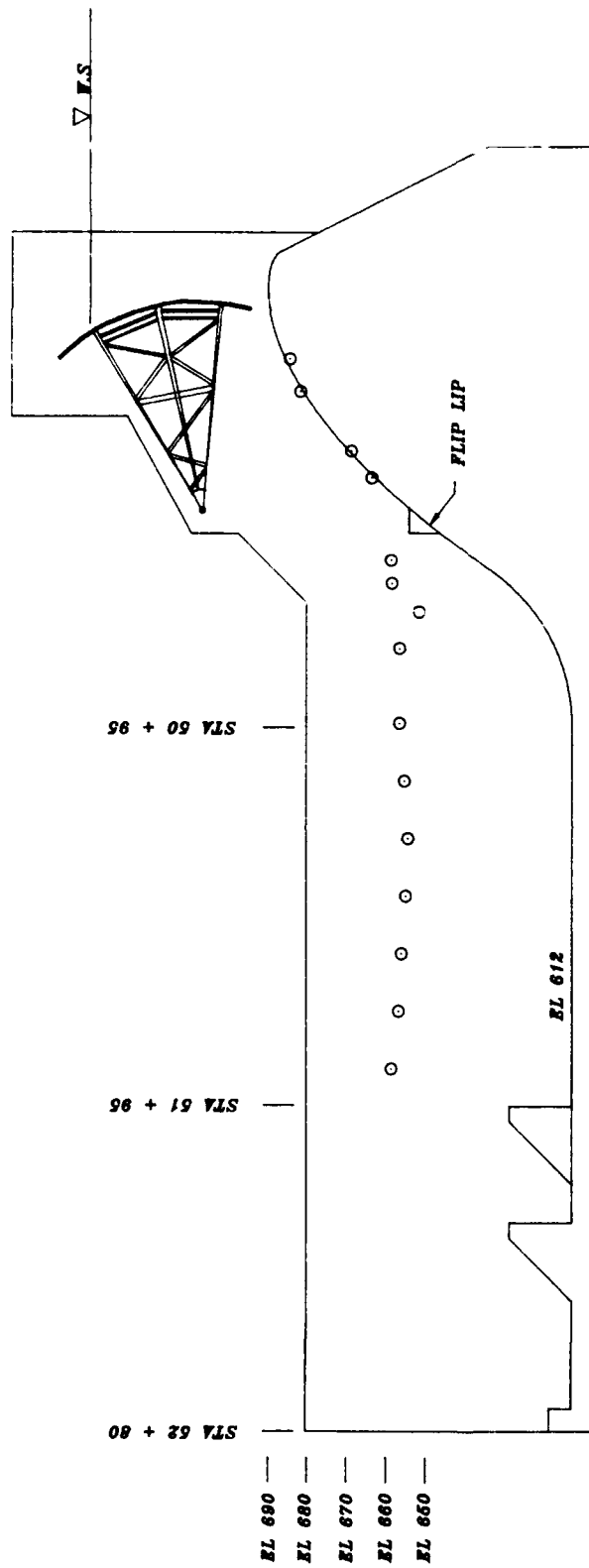




PROFILE OF STATIC PORT LOCATIONS



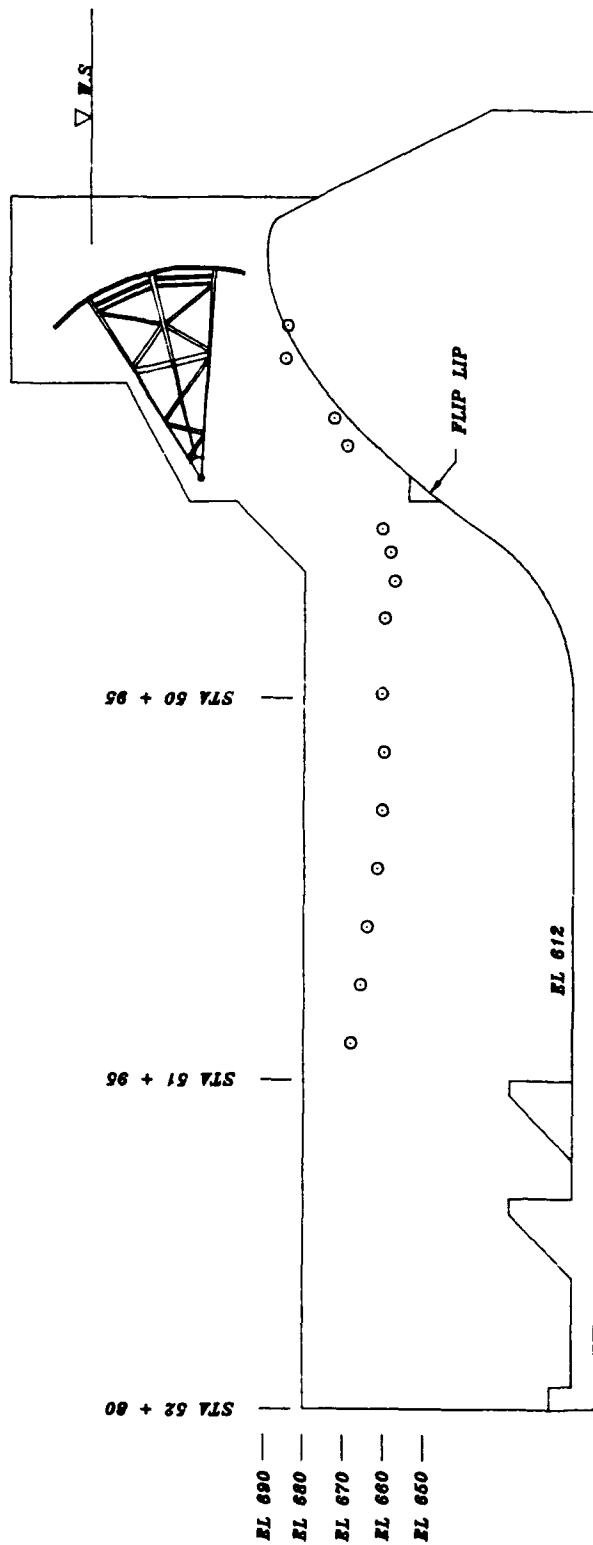
STATIC PORT ELEVATION'S



# **HYDROSTATIC PRESSURE PROFILE**

DISCHARGE :

- SPILLWAY 49,000 CFS
- POWERHOUSE 29,000 CFS
- SPILLWAY GATES 1, 2 OPEN 4.7 FT.
- SPILLWAY GATE 3 OPEN 8.7 FT.
- SPILLWAY GATE 4 OPEN 12.7 FT.
- POOL EL 738.7, TAILWATER EL 665.3



# **HYDROSTATIC PRESSURE PROFILE**

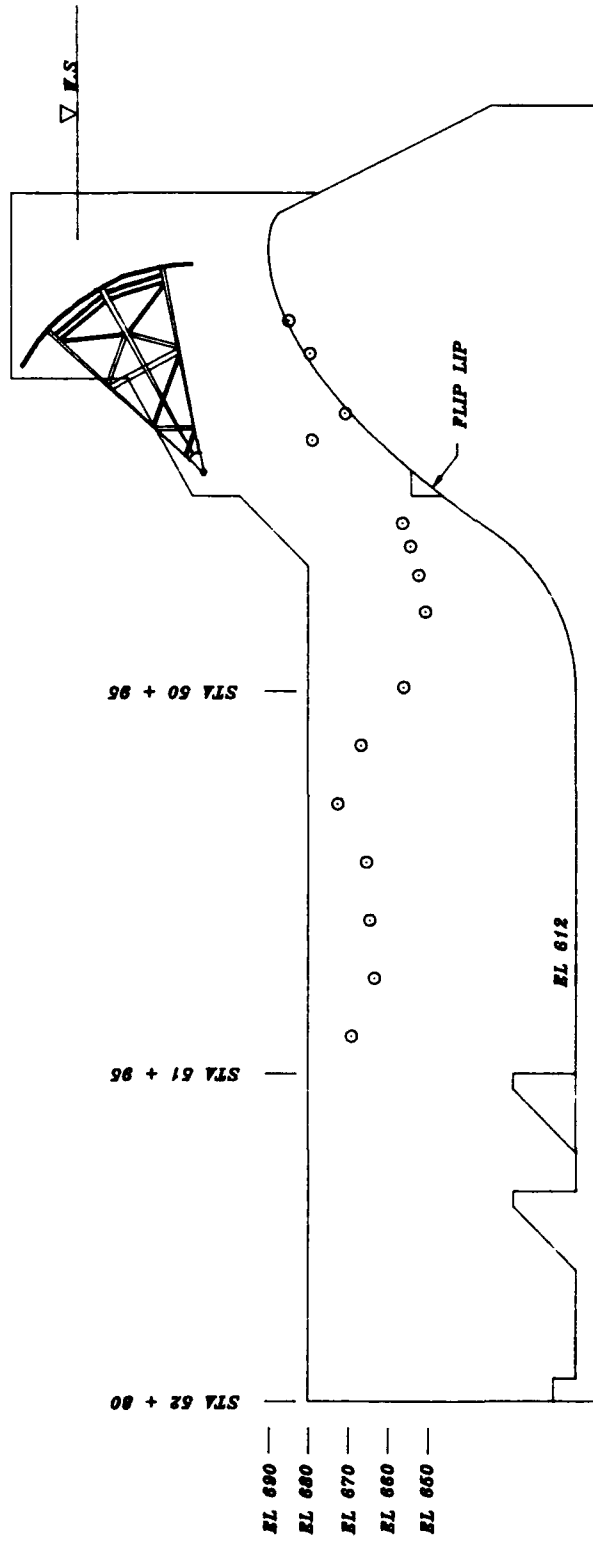
DISCHARGE -

SPILLWAY 47,000 CFS

POWERHOUSE 29,000 CFS

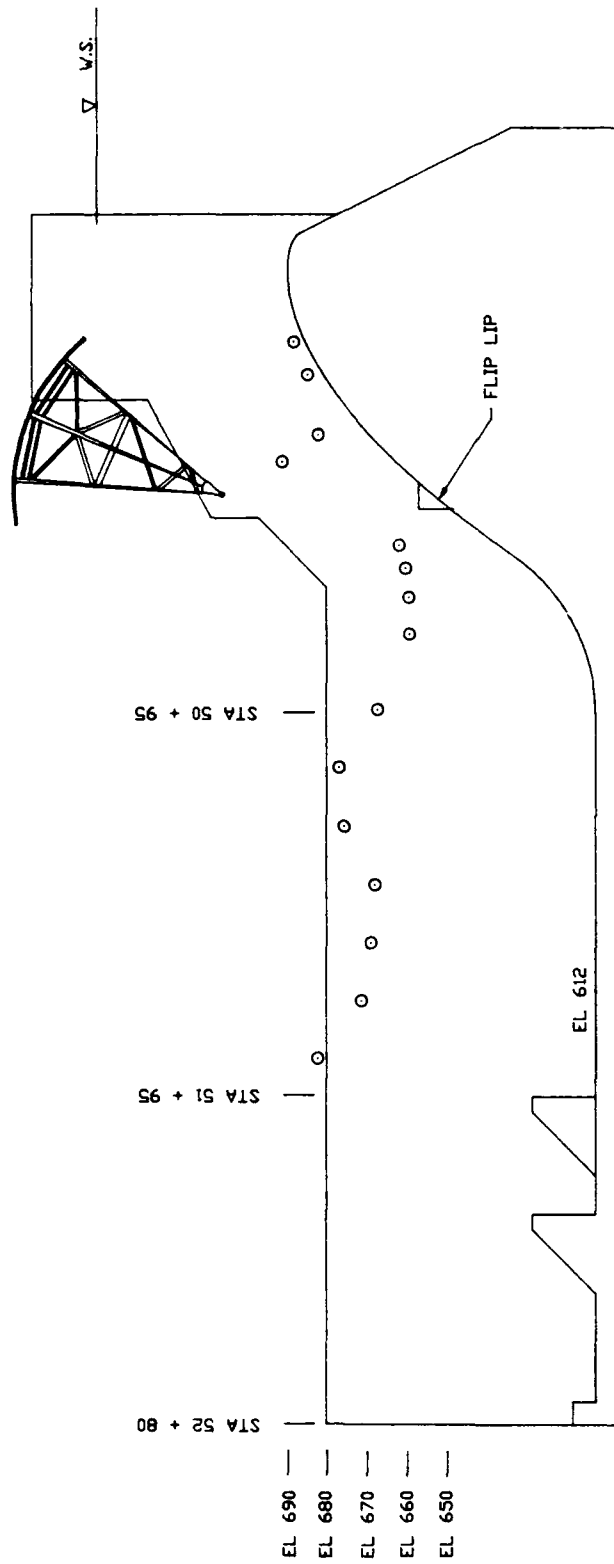
SPILLWAY GATES 1-4 OPEN 7.7 FT

POOL EL 736.7, TAILWATER EL 665.4



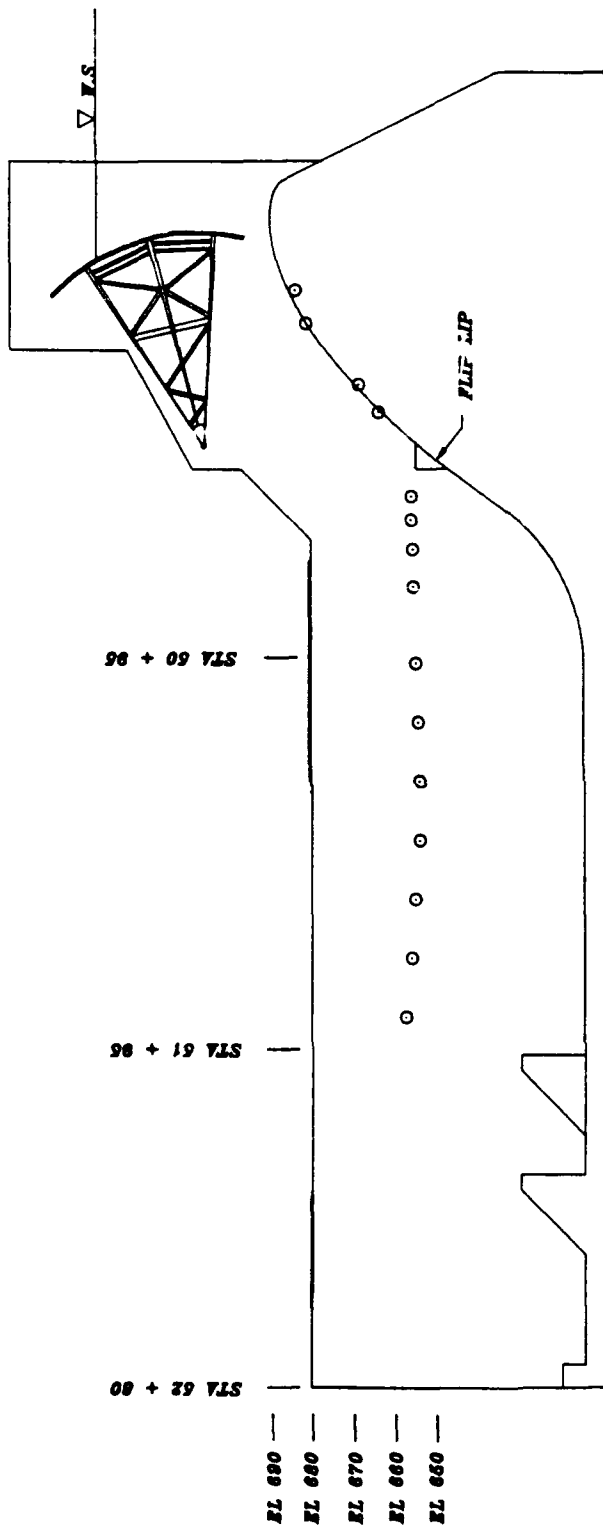
# **HYDROSTATIC PRESSURE PROFILE**

DISCHARGE 1  
 SPILLWAY 100,000 CFS  
 POWERHOUSE 32,500 CFS  
 SPILLWAY GATES 1-4 OPEN 19 FT  
 POOL EL 742, TAILWATER EL 668.3



# **HYDROSTATIC PRESSURE PROFILE**

DISCHARGE 1  
 SPILLWAY 229,000 CFS  
 ALL POWERHOUSE GATES CLOSED  
 ALL SPILLWAY GATES FULL OPEN  
 POOL EL 742.0, TAILWATER EL 675.0



# **HYDROSTATIC PRESSURE PROFILE**

DISCHARGE :

SPILLWAY 32,000 CFS

POWERHOUSE 29,000 CFS

SPILLWAY GATES 1-4 OPEN 6.2 FT

POOL EL 736.7, TAILWATER EL 664.5